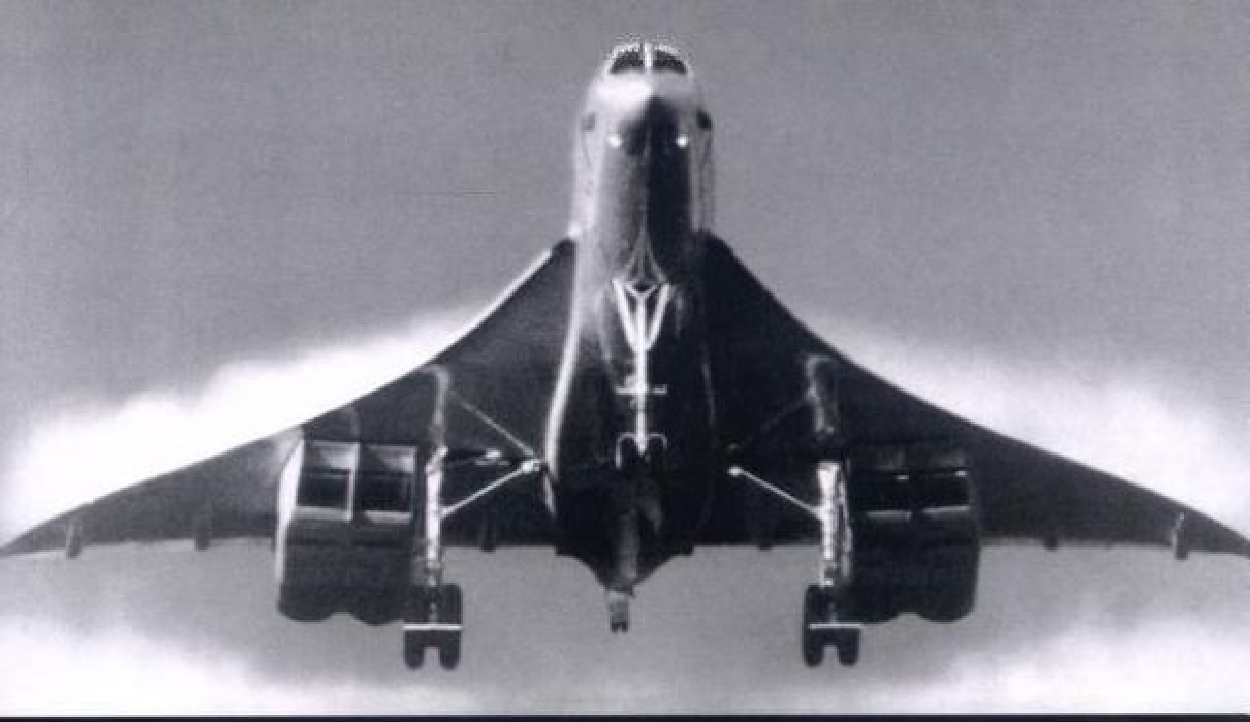

Human Performance and Limitations in Aviation

Third Edition

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Blackwell Science

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Third edition

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Preface

Travel by air is a relatively safe means of transport, and there has been a great improvement in the accident rate since 1960. This is due to enhancements in technology, manufacturing standards, maintenance, operational procedures and training.

However, human error continues to be cited as a major cause in over 70% of aviation accidents. It is widely agreed that a better understanding of human capabilities and limitations, both physical and psychological, could contribute to a reduction in human error and improve flight safety.

The first edition of this manual was published in 1991 to provide a readable introduction to the basic concepts of human factors in aviation. There was recognition of a particular need for the enhancement of judgement and decision making, particularly amongst private pilots, and the manual was aimed at increasing the necessary knowledge.

In 1992 the UK Civil Aviation Authority introduced an examination in Human Performance and Limitations for applicants for all private and professional pilot licences. In Europe, the Joint Aviation Authorities have published the Joint Aviation Requirements for Flight Crew Licensing (JAR-FCL 1) which was adopted in 1996 and implemented 1 July 1999. Subpart J details the syllabus for the Human Performance and Limitations examination and this manual has been completely revised and rewritten to encompass the syllabus requirements.

The opportunity has been taken to remove some information which, although of interest to pilots, is not a requirement for the JAR-FCL examination and is readily available from other sources (e.g. the chapter on first aid). The coverage of basic aviation psychology has been greatly expanded although, continuing the principle of the first edition, consciously avoiding the use of excessive

jargon and technical language. The basic aviation physiology section now includes topics on the high altitude environment and on health maintenance.

Ron Campbell died in 1996. The first edition of this manual evolved from his belief in the importance of teaching judgement and decision making in flying training. It is a privilege to continue his vision in the preparation and production of this third edition.

Since preparation of the second edition of this manual in April 1999, the JAA have expanded the knowledge requirement of applicants for professional pilot licences. Also, training in Multi Crew Co-operation (MCC) is now a mandatory requirement for gaining a JAA Air Transport Pilot Licence (ATPL), and this manual covers the syllabus for the human factors module. It also provides material for training in Crew Resource Management (CRM) and for Simulated Flight Instructor (SFI) core courses.

Although this manual encompasses the syllabus requirement for flight crew licensing, the original objective of covering the basic concepts of human factors in aviation remains unchanged. Aviation is truly international and this easy-to-read manual will be of interest and value to all aviation professionals, medical practitioners and human factors specialists world-wide.

I am grateful for the assistance of Laurie Benn and Brian Johnston of the Department of Civil Aviation Studies, London Guildhall University, in ensuring that this manual continues to meet the requirements of subpart J of JAR-FCL 1. However, any errors or omissions are mine.

Michael Bagshaw
September 2001

Part 1
Human Factors: Basic Concepts

Chapter 1

Human Factors in Aviation

1.1 Competence and limitations

To operate an aircraft safely, a pilot must have an understanding of technical subjects such as aircraft engines, instruments, meteorology and navigation. To make the appropriate decisions for the safe operation of an aircraft, the pilot must exercise judgement. This is based on training, knowledge and experience, and an appreciation of all the factors which could influence the current situation, including human factors. Training in human factors is a requirement of the International Civil Aviation Organisation (ICAO).

There is an interface between flight crew, machine, systems, equipment and software, which come together in the airspace environment. Edwards, a psychologist, presented the concept at a technical symposium dealing with man and machine, in 1972. He described it as the SHEL concept (see Figure 1.1):

- **S** indicates the software – the procedures and rules which have to be followed, checklists, symbology, etc.
- **H** is the hardware – the aircraft, its systems and equipment
- **E** is the environment in which the man/machine system operates
- **L** is the liveware – the crew who operate the aircraft and interact with other personnel.

L sits at the centre of the SHEL, because the liveware interfaces with all the other components.

Just as the aircraft structure, systems and software have structural and performance limitations, so the individual who makes up the liveware is subject to limitations of human performance. Some of these limitations will vary from day to day and between individuals,

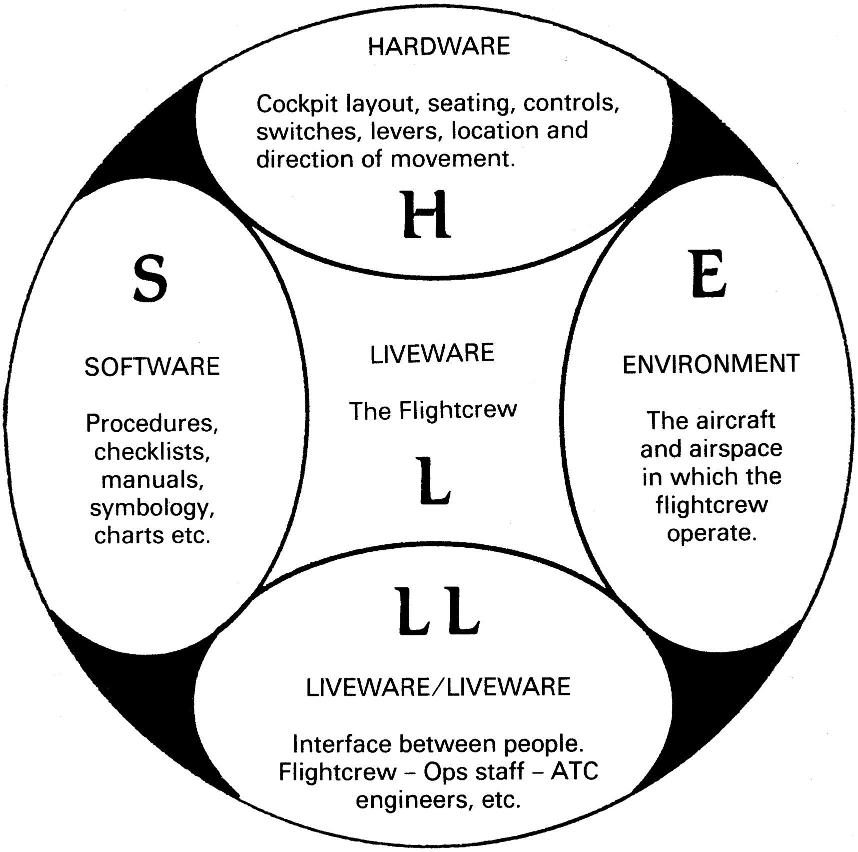

Fig. 1.1 The SHEL concept.

whereas other absolute limitations vary little between different people.

Flying an aircraft is a psycho-motor skill which can be learned by applying theoretical knowledge during practical training. This comes more easily to an individual who possesses some basic aptitude, but constant reinforcement of the acquired psycho-motor skills is necessary throughout a flying career to maintain competence in the flying environment.

The pilot has a duty of care to other crew members, passengers, other users of the airspace and to the general public. It is a legal requirement for the pilot to be fit to fly, whether flying professionally or for pleasure. Fitness is a complex interrelationship between physiological, psychological and emotional aspects of well-being.

It is important to remember that flight safety involves all those participating in aviation activity including management, the providers of support services (such as meteorological forecasting and flight planning), engineers and the regulatory authorities, not just the pilot. There must be an understanding of the potential conflict between resource availability, commercial considerations and the need to get the job done.

Thus it is essential for all those involved in aviation to be aware of human performance and limitations and how these may influence competence and flight safety. This requires an understanding of basic aviation physiology, health maintenance and basic aviation psychology.

1.2 Becoming a competent pilot

The traditional flight training philosophy is based on knowledge, skill and experience. The development of psycho-motor proficiency leads to good handling skills, and is achieved by constant practice following demonstration by the instructor of the appropriate aircraft handling technique.

The new concept of a human factors approach to flying training includes consideration of the following factors:

- attitude development
- stress management
- risk management
- flight deck management
- crew co-ordination
- psycho-motor skills.

This has the objective of reducing human error by creating awareness of judgement and decision making, and the development of professionalism.

Assessment of competency must take account of all these factors. Professionalism suggests the involvement of learning or science, with an understanding of the broad issues and implications. Proficiency, on the other hand, implies expert dexterity in doing a task, but without consideration of the wider issues.

1.3 Accident statistics

Travel by air is a safe means of transport. A one in a million risk of being killed or seriously injured requires five hours travel by air, compared with five minutes travel on a bicycle or 30 minutes in a car or on foot (UK 1994 statistics).

Prior to 1960, the annual accident rate for scheduled air carriers was something over 60 per million departures. In the ten years to 1970, this rate improved dramatically to about one or two per million departures. Between 1980 and 1996, there were 621 global fatal accidents to jet and turboprop aeroplanes weighing more than 5,700 kg, resulting in 16,849 fatalities (source UK CAA CAP681). The fatal accident rate for all North American and European operators during this period was 0.37 and 0.52 per million departures respectively, with JAA full member operators achieving 0.35 per million.

As a result of the increase in world air traffic, the annual number of fatal accidents increased globally by 32% during the period 1980–1996. If this growth in fatal accidents were to continue, by the year 2010 it is predicted there would be an annual average of 44 fatal accidents (almost one per week), assuming the same accident rate per million departures. However, over the period 1990–1996 the trend was decreasing.

Half of these 621 fatal accidents occurred during the approach and landing phases of flight, and in 41% of fatal accidents the most frequently identified causal factor was 'Lack of positional awareness in the air'. The most frequently identified consequences were 'Collision with terrain/water/obstacle' and 'Controlled flight into terrain', followed by 'Loss of control in flight'.

Nearly 40% of all these fatal accidents involved aeroplanes which had not been fitted with currently available safety equipment, such as a ground proximity warning system (GPWS) or enhanced GPWS. In 88%, crew members were identified as a contributory causal factor, with 76% identifying crew as a primary causal factor. Only 11% of these fatal accidents to aeroplanes above 5,700 kg involved an aircraft primary causal factor.

In non-scheduled general aviation, the statistics are quoted as a fatal accident rate per 100,000 flying hours. For UK registered aeroplanes of 5700 kg and below, during the ten years prior to 1998, the average rate was 1.5, representing an average of twelve fatal

light aeroplane accidents per year. The main causes, accounting for 86% of fatal accidents, were:

- continued flight into bad weather, including impact with high ground and loss of control in instrument meteorological conditions (IMC)
- loss of control in visual meteorological conditions (VMC), including stalling/spinning
- mid-air collision
- over-running short runway
- collision with ground obstacles during approach to land
- fuel exhaustion
- impaired pilot performance due to alcohol or drugs.

Monitoring accident statistics allows trends to be identified, which can lead to changes in training and regulatory requirements.

1.4 Flight safety concepts

Improvements in technology, manufacturing standards, maintenance, operational procedures and training are responsible for much of the improvement in the accident rate since 1960. In the last 20 years, the proportion of accidents ascribed to human error has remained constant in excess of 70%. However, it should be noted that 'human error' does not imply 'pilot error'. Equally, flight crew error cited as a causative factor should be often more properly viewed as the flight crew's inability to break the chain of events leading to the accident. Nonetheless, there has been a human failing at some stage.

Human error will occur, no matter how good the training nor how competent the individual. The designers of aircraft systems and those who develop operational procedures have to allow for this basic human limitation, and build in fail–safety. Trainers have to ensure that crew members understand the importance of monitoring their own actions and those of the rest of the crew, and to have the confidence to give and accept challenges. This underlies the principles of crew resource management (CRM); it is important to realise that these principles apply equally to the pilot of a small light aircraft as much as to the crew of a large passenger jet airliner.

The goal of most airlines is to achieve a profit from the safe carriage of passengers and/or cargo to and from destinations around the world. All the humans involved in this activity have needs, and for the passengers to arrive safely and punctually at their destination with their baggage, the airline must provide a serviceable and correctly equipped aircraft. This can be achieved only by having an efficient infra-structure in place, which meets the human needs of the airline employees and so contributes to flight safety. The same argument relating human needs to flight safety applies equally to air traffic control, engineering and all other support services. Everyone within the aviation industry contributes to flight safety.

Part 2

Basic Aviation Physiology and Health Maintenance

Chapter 2

The Basics of Flight Physiology

The normal working of the human body when in flight can be influenced by altitude, pressure, temperature, acceleration and changes in perception.

2.1 The atmosphere

Composition

The atmosphere surrounds the earth and forms an elastic layer of air consisting of a number of concentric shells. The inner shell is the troposphere which extends to an altitude of 30,000 ft at the poles and 60,000 ft at the equator. The atmospheric air is composed of a mixture of gases and water vapour. The most abundant gases are nitrogen (78%) and oxygen (21%), with the remaining 1% being argon, carbon dioxide, neon, hydrogen and ozone. These proportions are constant up to the tropopause (approximately 36,000 ft). In addition, the atmosphere contains solid particles such as dust and sea salt. These are important in the development of certain types of weather such as clouds, mist and fog because moisture condenses on these particles.

The pressure at sea level in the standard atmosphere is 760 millimetres of mercury (mmHg) (29.92 inches Hg, or 1013.2 millibars) and this falls to half at 18,000 ft, where the ambient temperature is about minus 20°C. Knowing the percentages of the main gases present in the atmosphere, it is possible to calculate the gas pressure, in mmHg, given the atmospheric pressure at an altitude.

Figure 2.1 illustrates the reduction of atmospheric pressure with increasing altitude.

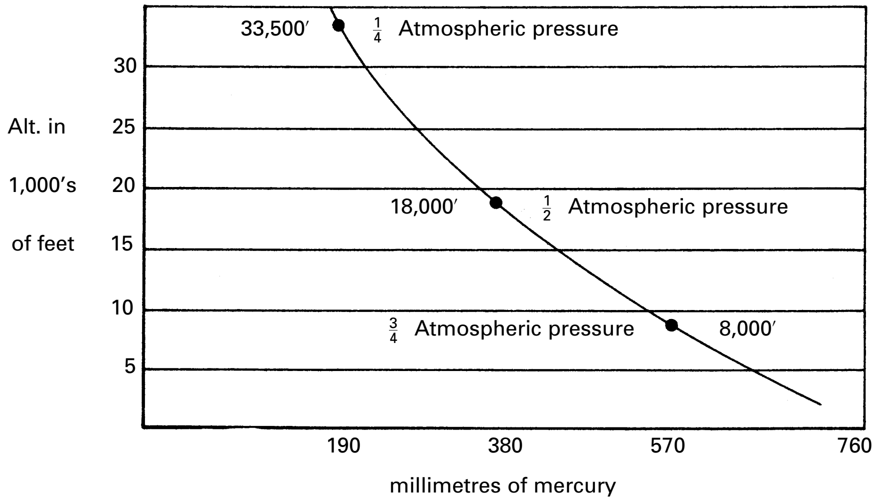

Fig. 2.1 Atmospheric pressure.

Altitude

Human physiology is influenced by the ambient pressure and composition of the atmosphere and the effects are related to altitude. Therefore it is important to understand which datum is being used.

In aviation, *altitude* is defined as the elevation above mean sea level. Since atmospheric pressure varies at the surface of the earth, a forecast is made of the pressure (in millibars or inches Hg) in a given geographical area for the next hour, and this is referred to as the QNH. Thus altitude is measured with reference to the QNH datum and is a measure of the vertical distance (in feet or metres) of an aircraft above mean sea level.

In aviation, *height* is a measure of the vertical distance of an aircraft above the airfield elevation. The atmospheric pressure is forecast at the airfield datum and this is referred to as the QFE. Thus an aircraft altimeter set to this datum will indicate zero on the ground at the airfield, and not the altitude above mean sea level (unless the airfield happens to be at sea level).

Because of the continuously changing atmospheric pressure, and because at any one time the pressure varies at different points of the earth's surface, the standard atmospheric pressure (1013.2 mb or 29.92 in Hg) is used as the datum pressure for en-route flying above a certain altitude. This altitude is referred to as the *transition altitude,* above which vertical distance is referred to as a *flight level*

(FL). The flight level is stated in 3 digits, representing hundreds of feet.

Thus FL290 means that the aircraft altimeter indicates 29,000 ft above the standard pressure datum of 1013.2 mb, and ensures that appropriate vertical separation can be maintained between all aircraft flying in the vicinity. It does not mean that the aircraft is at an altitude of 29,000 ft above sea level (unless the surface atmospheric pressure at that point happens to be 1013 mb).

On descent to the aerodrome, the datum is changed from the standard setting to the appropriate QNH at the *transition level*. This ensures terrain clearance by the aircraft, and allows an accurate approach profile to be flown to the runway.

Finally, the *cabin altitude* refers to the pressure being maintained within the aircraft cabin. This depends upon the establishment of a pressure differential between the cabin interior and the outside atmosphere. In a pressurised aircraft this means that the effective altitude experienced by the aircraft occupants may well be different from the actual aircraft altitude.

With respect to the physiological effects of altitude, figures are based on the ICAO standard atmosphere, i.e. assuming a pressure of 760 mmHg at sea level, where the temperature is +15°C. The mean temperature lapse rate is a reduction of 1.98°C per 1,000 ft from sea level to 36,089 ft, above which it is a constant –56.5°C.

The physical gas laws

Since air is a mixture of gases which exert pressure, have measurable mass and can be compressed, it is subject to certain established laws governing reaction to changes in pressure, temperature, volume and density.

Boyle's law states that

'*providing the temperature is constant, the volume of a gas is inversely proportional to its pressure*'.

This means that when the pressure increases, the volume decreases and conversely when the pressure decreases, the volume increases. Put another way, at a fixed temperature the pressure of the gas varies inversely with its volume. This is strictly correct only at moderate temperatures.

$$\frac{p1}{p2} = \frac{v2}{v1}, \text{ where } p = \text{pressure}, \ v = \text{volume}$$

Boyle's law explains some of the effects of altitude on the gas-containing cavities of the human body during flight. For example as altitude increases, the gas within the middle ear, sinuses and gastro-intestinal system will expand, sometimes with painful results.

Charles's law states that

'*the volume of a fixed mass of gas held at a constant pressure varies directly with absolute temperature*'.

A feature of gas expansion is that equal volumes of different gases expand by the same amount when heated to the same temperature. So provided the pressure remains constant, each degree centigrade rise in temperature will cause the gases to expand by 1/273 of the volume they would occupy at 0°C.

Another way of stating Charles's law is the volume of a fixed mass of a gas at constant pressure is directly proportional to its absolute temperature.

$$\frac{v1}{v2} = \frac{T1}{T2}, \text{ where } v = \text{volume}, \ T = \text{absolute temperature}$$

The gas laws of Boyle and Charles can be summarised by the equation:

$pv/T = \text{constant}$,
where p = pressure, v = volume, T = absolute temperature.

This is known as the gas equation, or General Gas Law, and it applies even when there is a change in all three variables, pressure, volume and temperature.

Dalton's law states that

'*the total pressure of the gas mixture is equal to the sum of its partial pressures*'.

This means that the proportion of oxygen remains 21% throughout the atmosphere, irrespective of the total atmospheric pressure at that level.

Henry's law states that

'*at equilibrium the amount of gas dissolved in a liquid is proportional to the gas pressure*'.

This means that the amount of gas in solution varies directly with the pressure of that gas. The relevance of this in aviation is that as altitude is increased and atmospheric pressure reduces, gases such as nitrogen will come out of solution in the body tissues. At high altitude this can lead to decompression sickness.

Fick's law states that

'the rate of gas diffusion through a tissue medium is proportional to the tissue area and the difference between the gas partial pressures on the two sides, and inversely proportional to the tissue thickness'.

This means that the transfer of gases, such as oxygen and carbon dioxide, through the alveolar membrane in the lungs (see 2.2, below) depends on the area and thickness of the membrane, and the partial pressures of the gases in the blood and in the lung alveoli.

2.2 The respiratory and circulation systems

Functional anatomy

The body tissues use oxygen to release energy to maintain life. The chemical reaction between oxygen and carbohydrate produces carbon dioxide, which is carried away from the tissues by the bloodstream to be excreted by the lungs and water. The utilisation of oxygen and production of carbon dioxide by the tissues is known as metabolism, which involves oxidation of carbohydrate from food to produce energy. This is respiration and it has three phases, each of which may be affected to some degree by flight:

(1) The exchange of gases between the body and the atmosphere
(2) The carriage of gases to and from the lungs and the site of oxidation (the tissue cells)
(3) The actual oxidation process in the cells, liberating energy.

Circulation is the term used to describe the passage of blood through the blood vessels (arteries, capillaries and veins). The

arteries have elastic walls and carry oxygenated blood from the lungs via the heart's left atrium and left ventricle to the tissues. The vessels in the tissues are the capillaries which have very thin walls to allow diffusion of oxygen into the tissue cells and carbon dioxide out of the cells into the blood. The deoxygenated blood is carried in the veins back to the lungs via the right atrium and right ventricle of the heart. The veins do not have elastic walls and the contraction of adjacent body muscles assists the flow of blood through the veins.

An adult body contains about six litres of blood. Just over half of this is plasma which is the liquid medium in which the blood cells are carried.

There are three kinds of blood cell, each with different functions.

Red blood cells (erythrocytes) contain haemoglobin which contains iron and is the major component of the red cells. This has a strong affinity for oxygen (and incidentally also for carbon monoxide, the affinity being 210 to 250 times greater than for oxygen). Anaemia is a condition in which the number of red blood cells is below normal and thus less oxygen can be carried from the lungs to the tissues. For this reason, it is recommended that flight crew engaged in regular flying do not donate blood. Red blood cells with their haemoglobin are manufactured in the bone marrow, and live for approximately 108 days. If an individual should decide to donate blood, a period of 24 hours should elapse before flying to ensure replenishment of the depleted red blood cells by the bone marrow. If bone marrow itself is donated, the minimum recommended time interval before flying is 48 hours to ensure recovery from the associated general anaesthetic.

The *white blood cells* consist of a number of types which have a range of functions. They engulf invading bacteria, they produce antibodies to resist attack by foreign invaders, they identify antigens and other foreign substances, they release anticoagulants and help combat inflammation, and they devour bacteria.

The remaining cells are *platelets* which are involved in blood coagulation.

The blood is pumped round the body by the heart. The heart has four chambers, two thin-walled upper chambers (atria) and two thick-walled lower chambers (ventricles). The two sides of the heart are separated by a muscular wall known as the septum. Each upper chamber is joined to the lower one by a valve which allows one-way

flow. The walls of the heart chambers are made up of a muscle type known as myocardium.

The function of the left ventricle is to pump oxygenated blood through the body circulatory system, to ensure the delivery of oxygen to the tissues. The right ventricle pumps deoxygenated blood, received from the body tissues, into the pulmonary artery of the lungs.

The atria have a weaker pump action than the ventricles. The left atrium receives oxygenated blood from the pulmonary vein of the lungs and moves it into the left ventricle, while the right atrium moves deoxygenated blood received from the body circulation into the right ventricle for onward pumping to the lungs.

During the cardiac cycle, the atria first contract, followed after a short pause by contraction of the ventricles. The contraction of the ventricles is felt as a pulse in the arterial system, and this is known as heart rate.

Blood pressure in the body is maintained within close limits by pressoreceptors in the arterial walls. The normal blood pressure is in the region of 120/80 mmHG (see Chapter 4, section 4.3, page 78), and this is controlled by variation in heart rate and tone of the arterial walls.

The effective volume of blood expelled by either ventricle per unit of time is the cardiac output. Thus cardiac output = stroke volume × heart rate, and the average for a healthy adult is 3.0 to 3.5 litres per minute.

To ensure its own blood supply, the heart has its own exclusive system of arteries, capillaries and veins, known as the coronary circulation. Anything interfering with this coronary supply can have fatal consequences. Narrowing or blockage of the coronary arteries or veins is known as coronary thrombosis or coronary atherosclerosis, and can lead to chest pain or sudden death (see Chapter 4).

Atmospheric air is breathed in through the nose, where it is filtered, moistened and warmed, and passes to the lungs via the trachea and appropriate bronchus. Each bronchus ends in a number of bronchioles which in turn end in the alveoli, millions of which form the lung tissue. The alveoli are thin-walled sacs (rather like balloons) which are surrounded by small thin-walled blood capillaries. The thin walls of the alveoli and capillaries allow gases such as oxygen and carbon dioxide to diffuse between atmospheric air in the

alveoli and blood within the capillaries. The tissue boundary is the alveolar membrane.

During respiration, air is drawn into the lungs by the actions of the diaphragm and intercostal muscles; when these muscles relax, the process is reversed so the air is breathed out. This cycle occurs 12–15 times a minute at rest.

The volume of gas which can be held in the lungs at the end of a maximum inspiration is called *total lung capacity*. For a typical average healthy adult this is about 6.5 litres. During normal breathing the volume of gas in the lung is about half total lung capacity (3 to 3.5 litres). At the end of normal expiration, some gas remains in the lungs and this is called *functional residual capacity* and is about 3 litres.

The volume of gas expelled from the lungs during normal expiration is called the *tidal volume*, and is around 0.5 litres. After normal expiration it is possible to forcibly expel a further volume of gas, but even then there will still be some gas remaining in the lungs. This is the *residual volume* and for a typical average healthy adult is about 1.5 litres. The difference between total lung capacity and the residual volume is called *vital capacity*, and in this example would be 5.0 litres (6.5–1.5).

Oxygen from the alveoli combines with the haemoglobin in the red cells of the blood within the capillaries, from where it is pumped by the action of the heart to the body tissues. A very small proportion of oxygen is carried in physical solution, although the majority is chemically combined with haemoglobin. In the body tissues the oxygen is released by the haemoglobin, and carbon dioxide is taken up by the blood to be returned to the lungs. Most of the carbon dioxide is carried in solution in the blood plasma, although about 5% is carried by haemoglobin.

The utilisation of oxygen in the body cells to produce energy is known as ‘internal respiration’. Unlike food or water, oxygen cannot be stored by the body. However, at any one time there is oxygen in transit, in combination with haemoglobin, thus giving an effective reserve of a minute or so. Carbon dioxide can accumulate in the tissues to a limited extent, but a build up of this waste product acts as a stimulus to respiration. The internal environment of the body tends to remain constant in spite of variations in external conditions. This is known as homeostasis.

The ventilation of the lungs is controlled so that the tensions of

oxygen and carbon dioxide in the arterial blood are maintained within very close limits. The most important factors controlling the level of ventilation (breathing rate) are the amount of carbon dioxide, the acidity of the blood and the amount of oxygen present in the arterial blood. There are receptors in the respiratory centre of the brain which respond to the carbon dioxide tension and the acidity of the arterial blood. An increase in either of these leads to an increase in breathing rate. The absence of any breathing at all is termed apnoea, and the condition of 'sleep apnoea' can occur in some individuals when there is a cessation of breathing whilst asleep. It is of concern only when the period of apnoea exceeds one minute.

Another set of chemoreceptors is located in the carotid arteries and these respond to changes in the tension of carbon dioxide in the arterial blood. These carotid receptors are also very sensitive to reduction in arterial oxygen tension.

It is important to note that the most powerful stimulus to respiration is caused by an increase in carbon dioxide tension rather than a reduction in oxygen tension in the blood. Thus the transfer of oxygen to the tissues is influenced by the presence of carbon dioxide.

The hypobaric environment

The atmosphere is compressible and has mass. The air at the surface of the earth is supporting the mass of air above it and its molecules will therefore be pressed close together, causing the density of the air to be greatest at the surface. At sea level the partial pressure of oxygen is more than adequate to support normal living activities. With increasing altitude, there is a fall in atmospheric pressure together with a decrease in density and temperature. Fortunately, the relationship between the oxygen saturation of haemoglobin and oxygen tension minimises the effect of the reduction in partial pressure of oxygen. Ascent to an altitude of 10,000 ft produces a fall in the partial pressure of oxygen in the alveoli but only a slight fall in the percentage saturation of haemoglobin with oxygen. However, once altitude rises above 10,000 ft the percentage saturation of haemoglobin falls quickly and this results in the condition of hypoxia. In fact, above 8,000 ft the effects of lack of oxygen will

begin to appear and a decrease in an individual's ability to perform complex tasks and a reduction in night vision can be measured.

Figure 2.2 shows the oxygen dissociation curve of blood. The concentrations of physically dissolved and chemically combined oxygen are shown separately. The curve illustrated is the average for a fit young adult. The actual shape of the curve will be influenced by factors such as age, state of health, tobacco abuse and ambient temperature.

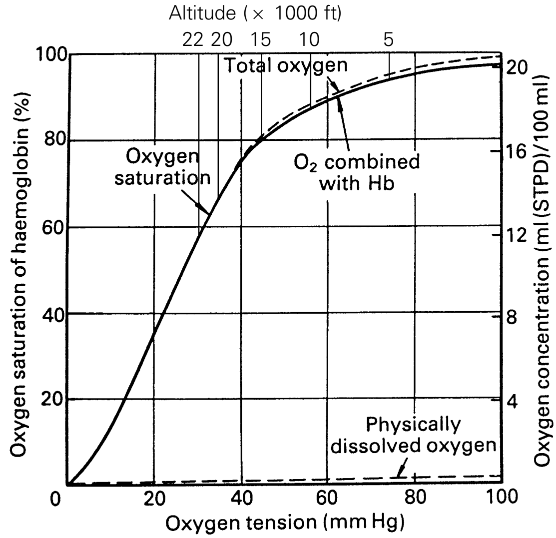

Fig. 2.2 The oxygen dissociation curve of blood.

At sea level the atmospheric pressure is 760 mmHg. The rate and depth of breathing is controlled by the metabolic demands of the tissues, and it has already been stated that the fundamental controlling factor is the partial pressure of carbon dioxide in the blood within the respiratory centre situated in the brain. It is extremely sensitive to small changes in the carbon dioxide tension in the blood, and continuously adjusts the breathing to maintain the tension at a normal level.

The composition of air in the alveoli of the lungs differs from that of atmospheric air due to constant diffusion of gases to and from the alveoli and the blood. Alveolar air includes water vapour and carbon dioxide generated by the body, which remains as a constant provided the respiratory rate remains constant and the body is at

rest. The total pressure remains the same (760 mmHg at sea level) and so to accommodate the water vapour and carbon dioxide (40 mmHg and 47 mmHg respectively) the pressure of oxygen and nitrogen is reduced. Whereas the partial pressure of oxygen in the atmospheric air at sea level is 160 mmHg, the partial pressure of oxygen in the lung alveoli is 103 mmHg.

At 10,000 ft in the standard atmosphere, the total atmospheric pressure reduces to 523 mmHg. The pressures of carbon dioxide and water remain the same but the partial pressure of oxygen falls to 55 mmHg. This can be viewed as the critical oxygen tension below which a deterioration in performance is apparent.

Oxygen can be supplied through a mask in ever increasing concentration such that the inspired mixture has the correct amount of oxygen to maintain a pressure of 103 mmHg in the lung. It will be necessary for the proportion of oxygen to increase as altitude is increased and it can be calculated that the altitude at which the barometric pressure will equal the alveolar oxygen pressure of 103 mmHg, plus the pressure of water vapour and the pressure of alveolar carbon dioxide, is 33,700 ft at which altitude the barometric pressure is 190 mmHg. Thus an individual breathing 100% oxygen at 33,700 ft has the same oxygen tension in the lung alveoli as breathing air at sea level.

Any ascent above 33,700 ft will lower the oxygen tension in the lung. The lung alveolar oxygen tension can fall to 55 mmHg before there is a deterioration in performance. Thus the limiting altitude for breathing 100% oxygen is that where the alveolar pressure has fallen to 55 mmHg, which occurs at an altitude of 40,000 ft. A summary of lung partial pressures is given in Figure 2.3, and of the body oxygen requirement in Figure 2.4.

Hypoxia

This can be defined quite simply as a lack of sufficient oxygen to meet the needs of the body tissues. Although the brain is only 2% of the body weight it uses almost 20% of the total oxygen uptake and is very susceptible to reduction in oxygen partial pressure. Thus the earliest effects of insufficient oxygen are the impairment of cerebral functions.

With an increase in altitude the air pressure decreases and above 10,000 ft there is insufficient oxygen available to maintain adequate

	Total pressure mm Hg	Oxygen mm Hg	Nitrogen mm Hg	Water vapour mm Hg	Carbon dioxide mm Hg
Sea level					
Atmosphere	760	160 (21%)	600	—	—
Alveoli	760	103 (14%)	570	47	40
10,000 ft					
Alveoli	523	55	381	47	40

Fig. 2.3 Alveolar partial pressures at sea level and 10,000 ft (from Dalton's law).

cerebral function. There is wide variation between individuals so it is not possible to predict the exact altitude at which physical and mental impairment may occur. Another difficulty is that because of the very nature of hypoxia, the pilot becomes the poorest judge of when he or she is suffering from its insidious effects.

	Atmospheric pressure mm Hg	Lung oxygen partial pressure mm Hg	Breathing gas
Sea level	760	103	Air
10,000 ft	523	55	Air
10,000 ft +	Reducing	103	Increasing oxygen concentration
33,700 ft	190	103	100% oxygen
33,700 ft +	Reducing	Falling	100% oxygen
40,000 ft	141	55	100% oxygen
40,000 ft +	Reducing	55 + *n*	100% oxygen under pressure *n*

Fig. 2.4 Summary of body oxygen requirement at altitude.

Susceptibility to hypoxia

The following factors increase an individual's susceptibility to hypoxia in flight:

- *Altitude* – the greater the altitude, the more rapid the onset
- *Time* – the longer the time of exposure, the greater the effect
- *Exercise* – exercise increases the demand for oxygen
- *Cold* – energy is required to generate heat to overcome low temperature, and this increases the demand for oxygen
- *Illness* – illness similarly increases the energy demands of the body
- *Fatigue* – fatigue lowers the threshold for hypoxia symptoms
- *Drugs/alcohol* – alcohol and drugs can depress brain function, thus reducing the tolerance of altitude
- *Smoking* – smoking produces carbon monoxide which binds to haemoglobin with a greater affinity than oxygen, thus reducing the amount of haemoglobin available for oxygen transport.

Symptoms of hypoxia

A common early symptom of hypoxia is a personality change in which the normal inhibitory forces of common sense tend to be diminished, not unlike the intoxicating effect of alcohol. This progresses to impaired thinking and judgement, slowing reactions, mental and muscular incoordination, diminished vision and hearing, and impairment of memory. Eventually, there is loss of consciousness and ultimately, death.

The symptoms are insidious at first and slow to develop, but progressive and more marked at altitudes above 10,000 ft. In all cases night vision is impaired from approximately 5,000 ft upwards.

Stages of hypoxia

All individuals who normally live around sea level will eventually show the general symptoms of hypoxia if exposed to altitude in excess of 10,000 ft, the time of useful consciousness being shown in Figure 2.5. The stages of hypoxia can be classified by performance decrement, which is dependent upon altitude and the resulting oxygen saturation of the blood.

Indifferent stage – occurs when breathing air at altitude of 0 to 10,000 ft, giving arterial oxygen saturation of 98 to 87%. Dark

Altitude (ft)	Progressive decompression	Progressive decompression	Rapid decompression
	Seated at rest	Moderately active	Seated at rest
20,000	20 min	10 min	5 min
25,000	5 min	3 min	2 to 2.5 min
30,000	1.5 min	45 to 60 sec	60 sec
35,000	45 sec	30 sec	25 sec
40,000	25 sec	18 sec	12 to 15 sec
43,000	18 sec	12 sec	12 to 15 sec

Fig. 2.5 Times of useful consciousness.

adaptation is adversely affected at altitudes as low as 5,000 ft, where visual sensitivity at night is reduced by approximately 10%. Performance of new tasks may be impaired, and a slight increase in heart and breathing rates occurs.

Compensatory stage – occurs when breathing air at altitude of 10,000 to 15,000 ft, giving arterial oxygen saturation of 87 to 80%. Cardiovascular and respiratory physiological responses provide some protection against hypoxia. Effects on the central nervous system become perceptible after a short period of time. These include drowsiness, decreased judgement and memory, and difficulty performing tasks requiring mental alertness or discrete motor movements. Short term memory loss can be detected from about 12,000 ft.

Disturbance stage – occurs when breathing air at altitude of 15,000 to 20,000 ft, giving arterial oxygen saturation of 80 to 65%. Normal physiological mechanisms no longer offer protection against hypoxia. Effects include headache, dizziness, somnolence, air hunger, euphoria and fatigue.

Critical stage – occurs when breathing air at altitude of 20,000 to 23,000 ft, giving an arterial oxygen saturation of 65 to 60%. Mental performance deteriorates and confusion or dizziness occurs within a

few minutes. Total incapacitation with loss of consciousness rapidly follows with little or no warning.

Time of useful consciousness

The time of useful consciousness (TUC) is the maximum length of time during which an individual can carry out some purposeful activity following a loss of oxygen supply. Time of useful consciousness is also referred to as the effective performance time (EPT), which is defined as the length of time an individual is able to perform useful flying duties in an environment of inadequate oxygen. The use of EPT more accurately refers to critical (functional) performance than does TUC.

Figure 2.5 shows the time of useful consciousness following the sudden loss of oxygen supply for a healthy individual at rest and moderately active, both for a progressive decompression and a rapid decompression.

Figure 2.6 shows the effective performance time for a healthy individual at rest at various altitudes. The range of time indicates the variation due to individual endurance, experience, physical exertion, and whether a rapid decompression occurred or the oxygen

Altitude (ft)	Effective performance time
18,000	20 to 30 min
22,000	10 min
25,000	3 to 5 min
28,000	2.5 to 3 min
30,000	1 to 2 min
35,000	0.5 to 1 min
40,000	15 to 20 sec
43,000	9 to 12 sec
50,000	9 to 12 sec

Fig. 2.6 Effective performance time.

supply was simply turned off at altitude (a progressive decompression).

Oxygen systems

For flight above 10,000 ft a supplementary oxygen supply must be available. The system may consist of a portable oxygen container and a mask, or a fixed installation with easily available masks fitted adjacent to the crew and passenger positions. There are various oxygen breathing systems available.

Dilutor demand

This is a flight crew oxygen system consisting of a close-fitting mask with a regulator that supplies a flow of oxygen according to cabin altitude. Regulators are designed to provide an appropriate proportion of oxygen and air, from a mix of 0% oxygen and 100% cabin air at cabin altitudes below 8,000 ft, gradually increasing the proportion of oxygen until, at approximately 33,000 ft, 100% oxygen and 0% cabin air is delivered. Oxygen is supplied only when the user inhales, reducing the amount of oxygen required.

Pressure demand

This is similar to dilutor demand equipment except that oxygen is automatically supplied under slight pressure at cabin altitudes above approximately 10,000 ft, with full pressure breathing above 38,000 ft.

Pressure demand mask with mask mounted regulator

This is a pressure demand mask with a regulator attached directly to the mask rather than mounted on the instrument panel or elsewhere within the flight deck. The mask mounted regulator eliminates the problem of a long hose which must be purged before oxygen is delivered to the mask.

Continuous flow oxygen system

This oxygen system is typically provided for passengers. The passenger mask includes a re-breather bag which collects the user's exhaled air to be re-inhaled. The oxygen in the re-breather bag is replenished by a continuous flow of oxygen regulated as for dilutor demand regulated equipment. Because only a portion of the oxygen is consumed during each breath, the air in the re-breather bag

remains highly saturated with oxygen and is drawn into the lungs at the beginning of inhalation. If the bag if depleted before the breath is completed, cabin air is used in the remainder of the inhalation.

Cabin pressurisation

For prolonged flight above 10,000 ft, the use of supplemental oxygen via a mask is both tiring and inefficient. An alternative method of maintaining an adequate partial pressure of oxygen is to pressurise the aircraft cabin to ensure the cabin altitude remains below 10,000 ft, irrespective of the actual altitude of the aircraft. The cabin air supply is provided by tapping bleed air from the aircraft engine or by using an independent compressor, and the pressure within the cabin is controlled by an outflow valve. Maintaining the cabin at sea level pressure would require an extremely strong (and thus heavy) fuselage structure which would adversely affect weight and hence fuel economy.

We have seen that normal healthy individuals can tolerate altitudes of up to 10,000 ft with no harmful effects. However, in the case of the elderly or individuals suffering from diseases of the respiratory or circulatory system, they are less able to tolerate the mild hypoxia at this altitude. Accordingly pressurised cabins are designed to maintain an altitude in the region of 6,000 ft which gives an effective compromise between the physiological needs of the crew member or passenger and the economy needs of the aircraft operator.

Rapid decompression

If cabin pressure is suddenly lost during flight, pressure inside the aircraft will be forcefully equalised with outside air, with the cabin air being rapidly expelled. The magnitude and rate of this decompression, and the physiological effect on the occupants, will be determined by:

- the size of the cabin rupture or number of lost windows
- the altitude of the aircraft
- the amount of pressure differential between the cabin and the external environment
- the volume of the cabin
- the position of the rupture or lost window – the venturi effect –

can lead to a further increase in cabin altitude if cabin air is sucked out.

The larger the rupture and the smaller the cabin and the greater the pressure differential between the cabin and the outside air, the more rapid will be the rate of decompression. The term 'explosive decompression' is used to denote an extremely rapid loss of cabin pressure, although this is rare. However, when it does occur, a mist may form in the cabin due to the sudden change in temperature which can be incorrectly interpreted as smoke or fumes.

A sudden equalisation of pressure means a very strong blast of air outwards from the cabin opening. This may cause loose items or even persons to be sucked out. Therefore when flying in a pressurised aircraft at high altitude it is advisable to keep seat belts fastened at all times when seated, which will also provide restraint if unexpected turbulence is encountered.

Within the body cavities free gases will expand and will be expelled where possible. If decompression is relatively slow, the body gases will escape without difficulty. The middle ear and the sinuses will be ventilated fairly easily because the higher pressure within the cavities forces open the Eustachian tube (which connects the middle ear to the back of the nose) and the sinus openings.

If the decompression is rapid, gases expanding inside the intestinal tract may cause some pain. However the intestine is normally capable of significant stretching, and serious injury is unlikely. The same applies to the lungs because the lung gas is usually expelled through the trachea with little resistance. Following decompression the occupants will be exposed to hypoxia and the risk of decompression sickness. For this reason oxygen masks must be available at all times when flying pressurised aircraft.

Decompression sickness

In addition to the gases trapped in the body cavities, a considerable volume (primarily nitrogen) exists elsewhere within the body, not in its normal gaseous state but in solution.

As altitude increases this gas comes out of solution as bubbles and these can produce discomfort or pain around the joints or muscles – 'the bends'.

Similar bubbles can form in the lung tissue, recognisable by a

burning sensation or a stabbing pain in the chest, a cough and some difficulty in breathing – a condition known as ‘the chokes’.

Bubbles affecting the nervous system can lead to difficulty in muscular co-ordination and this gives rise to the condition known as ‘the staggers’.

Finally bubbles can form in the skin and this gives an itching sensation known as ‘the creeps’, or formication.

Decompression sickness seldom occurs below 25,000 ft and hardly ever below 18,000 ft, but this will vary with the individual and it is essential to descend to lower altitudes whenever the condition is suspected.

Prevention and treatment

Decompression sickness can be prevented by pre-breathing 100% oxygen before flight in order to ‘wash out’ nitrogen dissolved in body tissues. The length of time for pre-breathing depends upon the planned flight altitude. There is a risk of developing decompression sickness if flying within 12 or 24 hours of SCUBA diving, depending on the depth of the dive (see Chapter 4, section 4.5).

In the event of a rapid decompression at altitude, following the donning of masks and establishment of a supply of 100% oxygen, a rapid descent to below 25,000 ft and a slower descent to below 18,000 ft should prevent the development of decompression sickness.

Symptoms of decompression sickness in flight should be treated with 100% oxygen and the individual should be kept warm and still. Emergency post-flight treatment in a recompression chamber may be necessary on landing, and medical advice should be sought as soon as possible, preferably by radio communication prior to landing.

(Also see Chapter 4, Section 4.5 ‘Flying after SCUBA diving’.)

Barotrauma

When climbing to higher altitudes the body is exposed to reduced pressure externally. However, pressure within the body cavities remains the same as it was on the ground and so the gases inside begin to expand in accordance with Boyle’s law. The human body contains a significant amount of gas which is largely air. Some is dissolved in body fluids. Air also exists as a free gas in the intestinal

tract, the middle ear and the sinuses, where it expands as altitude is increased.

Expansion of gases trapped in the sinuses may lead to headache, trapped gas within the middle ear will cause ear pain and gas trapped in the stomach will give a feeling of abdominal fullness. Gas trapped in the small intestine can cause considerable pain on expansion which may on occasions lead to fainting. At 8,000 ft trapped gas expands by about 20% when compared to the volume at ground level. The faster the rate of climb, the greater the risk of discomfort or pain.

Finally bear in mind that gas can be trapped in recently filled teeth, in dental decay or dental or gum abscesses. This leads to a condition known as aerodontalgia in which pain can reach levels which can impair the ability to pilot an aircraft.

To reduce the risk of barotrauma:

- don't fly when suffering from a cold or congestion of the upper respiratory tract
- avoid eating gas forming foods
- avoid eating too quickly or eating too much because of the risks of swallowing air
- do not fly within 24 hours of receiving dental treatment
- avoid drinking large quantities of gassy fluids.

Hyperventilation

Hyperventilation may be defined as breathing in excess of the metabolic needs of the body. One of the waste products of metabolism is carbon dioxide which is carried to the lungs in the bloodstream. The rate of breathing is controlled by the respiratory centre of the brain and this reacts to the amount of carbon dioxide in the bloodstream. For example, during physical activity the body cells use more oxygen and therefore more carbon dioxide is produced. This causes the respiratory centre to produce a faster rate of breathing. However, if a faster rate of breathing takes place without an increase in physical exertion, extra oxygen is not required so extra carbon dioxide is not produced. The excessive breathing removes carbon dioxide from the bloodstream faster than it is produced by metabolism leading to chemical changes within the blood. This is hyperventilation.

Causes of hyperventilation include:

- anxiety
- stress
- excitement
- motion sickness
- vibration
- heat
- acceleration ('G' forces)
- pressure breathing
- hypoxia.

The symptoms associated with hyperventilation are:

- dizziness
- increased sensation of body heat
- tingling sensation in the fingers and toes
- increased heart rate
- nausea
- blurred vision.

In extreme cases, loss of consciousness can occur but when this happens the breathing rate slows and respiration becomes normal again and there is rapid recovery.

The symptoms of hyperventilation are similar to those of hypoxia and it is important to be aware of how hyperventilation can be caused and the precautions to avoid it. Re-breathing air exhaled into a paper bag will slow the breathing rate and stop hyperventilation, by restoring the normal acid-base balance (inhaling carbon dioxide increases blood acidity, which decreases the breathing rate). It can be avoided by understanding the signs and symptoms and maintaining a normal rate of respiration.

Effects of acceleration

Acceleration is the rate of change of velocity with time and occurs when the speed or direction of motion of a body alters. The magnitude (G) of an acceleration is expressed in multiples of the acceleration due to gravity (g), which is sensed as weight.

G = acceleration/g

The actual force of 1 G for an object is equivalent to the weight of that object. A person at rest is subject to the normal pull of gravity, i.e. 1 G, but if acceleration takes place in terms of speed or direction the G is increased. For example if pulling out from a dive the pilot could experience 2 G or more, which is the equivalent of a person weighing 90 kg suddenly increasing apparent weight to 180 kg. So the accelerated force is measured in G or multiples of the force of gravity.

In addition, acceleration may be described by the means by which it is produced, i.e. linear, radial or angular acceleration. The pilot's physiological response to this acceleration will be determined first by its magnitude and second by the duration and direction of its action. Duration is classified as either long (greater than 1 second) or short (1 second or less).

The body responds to inertial force, which by Newton's third law of motion is equal and opposite to the applied accelerative force. Thus when pulling out of a dive, the headwards acceleration of the pilot produces a footwards inertial force and this is referred to as + Gz.

Acceleration fore and aft (the horizontal plane) is referred to as Gx, whereas Gy is acceleration in the lateral plane (side to side). In normal aviation activity, acceleration is more likely to be encountered in the vertical plane (Gz). However short duration acceleration or deceleration, such as may occur in an accident, can affect any of the planes but particularly the horizontal. Tolerance to G forces depends on body orientation with respect to the direction of the applied force. Maximum human tolerance to acceleration is in the horizontal plane, and is in the order of 45 Gx.

The forces experienced with positive Gz result in a reduction in hydrostatic pressure within the blood vessels above the heart (i.e. supplying the brain) and an increase in hydrostatic pressure below the heart. The first symptom caused by increasing positive Gz is reduction in peripheral vision, followed by a narrowing of visual field and then if the G force continues beyond +2Gz, the condition known as 'grey out'. The cause of this phenomenon is that the pressure within the eye, the intra-ocular pressure, of 20 mmHg will abolish retinal blood flow once the arterial blood pressure falls below this value. If the G force reaches +4Gz the next stage will be a

total loss of vision (black out) during which hearing and mental function are retained, and this will be followed by loss of consciousness (G-LOC). G-LOC may occur within 4 to 6 sec of rapid onset of +Gz.

Modern fighter aircraft are capable of sustaining accelerations of +8 to +10 Gz for periods up to 60 sec. These levels can be attained very quickly with the rapid onset reaching the limits of human tolerance.

Protection against the effects of +Gz can be assisted to some extent by using a reclining seat, which effectively reduces the distance, and hence the hydrostatic pressure, between the heart and the brain. Additional protection is given by wearing an anti-G suit. This applies pressure to the lower limbs and abdomen during high G manoeuvres to prevent pooling of blood in the extremities and so enables the maintenance of hydrostatic pressure above the heart. Additional protection can be provided by the use of positive pressure breathing during acceleration, which also assists in the maintenance of hydrostatic pressure.

The force of negative G is experienced during a rapid bunting manoeuvre or pushover and this results in the blood and the body organs being displaced towards the head. This increases blood pressure in the cranium and distends the small blood vessels of the face and the eyes. The face becomes flushed, with a sensation of fullness in the head and eyes ('red out').

Tolerance to G forces varies between individuals. Factors which decrease G tolerance include hypoxia, hyperventilation, and hypoglycaemia (low level of glucose in the blood). Alcohol and smoking also reduce G tolerance as do poor physical fitness and fatigue.

2.3 The high altitude environment

It has been described how supplementary oxygen systems will give protection against hypoxia at cabin altitudes above 10,000 ft. The proportion of oxygen in the gas mix reaches 100% at 33,700 ft and this will continue to give protection up to a cabin altitude of around 40,000 ft. An individual breathing 100% oxygen at 33,700 ft has the same partial pressure of oxygen in the lungs as a person breathing air at sea level. At 40,000 ft a person breathing 100% oxygen will have the same partial pressure in the lungs as a person breathing air

at 10,000 ft. Therefore 33,700 ft is the highest altitude at which an individual has complete protection from the effects of hypoxia, and 40,000 ft is the highest altitude at which 100% oxygen will provide reasonable protection for the time needed to descend to a safe altitude. Above 40,000 ft it is necessary for 100% oxygen to be delivered under positive pressure to maintain an adequate partial pressure of oxygen and prevent the onset of hypoxia. Breathing with positive pressure is tiring due to the reversal of the normal breathing cycle. It requires training and is used only as an emergency facility to enable a rapid descent to below an altitude where pressure breathing is not necessary.

Ozone

Natural ozone is formed primarily above the tropopause in the upper atmosphere as a result of the action of UV light on oxygen molecules. The amount and distribution of natural ozone in the atmosphere varies with latitude, altitude, season and weather conditions. The highest concentrations in the northern hemisphere are generally found at altitudes above 40,000 ft over high latitude locations during the winter and spring.

The effects of high ozone concentration on human beings can include eye irritation, coughing due to irritation of the upper respiratory system, nose irritation, chest pains and headache.

As a result of this, the Federal Aviation Administration (FAA) in the USA has regulations requiring that a transport category aeroplane operating above flight level 180 must show that the concentration of ozone inside the cabin will not exceed 0.25 parts per million by volume (ppmv), sea level equivalent, at any time and the time weighted value of 0.1 ppmv, sea level equivalent, for scheduled segments of more than four hours.

Similar regulations are proposed by the European Joint Aviation Authorities (JAA).

Ozone is broken down into oxygen at temperatures in excess of 400°C.

Most long haul transport jet aircraft are equipped with ozone catalytic converters which break down or ‘crack’ the ozone before it enters the cabin air circulation. Ozone is unlikely to be a problem for crew and passengers of general aviation light aircraft, which do not fly at sufficiently high altitudes to encounter ozone.

Cosmic radiation

Natural radiation consists of cosmic rays from outer space and the gamma rays from rocks, earth and building materials. Cosmic (or galactic) radiation is produced when primary photons and alpha particles from outside the solar system interact with components of the earth's atmosphere. A second source of cosmic radiation is the release of charged particles from the sun which become significant during periods of solar flare ('sun storm'). This should not be confused with solar radiation which is the source of terrestrial light. Solar radiation ('sunshine') contains ultra-violet (UV) light, which can cause ageing of skin (UVA radiation) and skin cancer (UVB radiation) in susceptible individuals exposed to too much sunlight. Solar flare (from a sun storm) is a source of cosmic radiation and is not associated with the development of skin cancer. Cosmic (or galactic) radiation is of low intensity, predictable and increases with altitude.

Protection from the effects of solar flare is provided by the earth's atmosphere, and theoretically it may be necessary for aircraft flying at very high altitudes (such as the Concorde supersonic transport aircraft) to descend during a solar flare. In practice this has not been necessary during such events.

High levels of radiation, such as that from a nuclear explosion, will cause severe cell damage in a human being, particularly to the bone marrow cells and the reproductive cells, which cannot be repaired by the body. It is more difficult to predict the effects of low level doses of radiation, such as cosmic radiation or medical X-rays, because in most cases any cell damage is repaired satisfactorily by the body's own mechanism. It is not possible to predict a maximum safe threshold of exposure, because individuals vary in their biological response.

Workers in the nuclear industry and those who work with X-rays may be designated as classified workers and have their occupational radiation exposure monitored and recorded. In 1991 the International Commission on Radiological Protection (ICRP) recommended that exposure of crew to cosmic radiation in jet aircraft should be considered part of occupational exposure. The ICRP recommends maximum mean body effective dose limits of 20 milli-Sieverts per year (mSv/year) (averaged over five years) for classified workers and 1 mSv/year for the general population, with an

additional recommendation that the equivalent dose to the foetus should not exceed 1 mSv during the declared term of pregnancy.

The Council of the European Union has adopted a directive laying down safety standards for the protection of the health of workers and the general public against the effects of ionising radiation. Article 42 which deals with protection of aircrew states that for aircrew who are liable to be subject to exposure of more than 1 mSv/year, appropriate measures must be taken, in particular:

- assess the exposure of the crew concerned
- take into account the assessed exposure when organising working schedules with a view to reducing the doses of highly exposed aircrew
- inform the workers concerned of the health risks their work involves
- apply special protection for female aircrew during pregnancy.

Records of cosmic radiation exposure are maintained for flights at altitudes in excess of 49,000 ft. Within Europe the Ionising Radiation Regulations set the boundary for determining whether or not a worker should be classified at 6 mSv/year. This is an arbitrary level of three-tenths of the permitted maximum exposure and although it has no radiobiological significance, it has long been an accepted level for the radiological classification of workers in the European nuclear industry.

Measurement and calculation of cosmic radiation exposure of crew and passengers in commercial aircraft confirm that none exceed the 6 mSv level. Also there is no evidence from epidemiological studies of flight crew of any increase in incidence of cancers linked to ionising radiation exposure, such as leukaemia.

Cosmic radiation is of no significance at altitudes below about 25,000 ft because of the attenuating properties of the earth's atmosphere. Attenuation is also provided by the earth's geomagnetic field, so the dose received by an individual depends on latitude, altitude, time of year and the point in the solar cycle.

For the occupants of the Concorde supersonic transport aircraft, the effective dose rate at cruising altitude has been measured in the range 12 to 15 micro-Sieverts per hour (μSv/hour). On ultra long-haul flights at high latitudes, such as a Boeing 747-400 flying between London Heathrow and Tokyo Narita, the effective dose

rate at cruising altitude is around 5 μSv/hour. On short-haul commercial operations, the effective dose rate in Europe is in the region of 1 to 3 μSv/hour.

For typical annual flight schedules, crew members accumulate around 4 or 5 mSv per year on Concorde and long-haul operations, and between 1 or 2 mSv per year on European short-haul operations, from cosmic radiation.

Background levels of radiation from ground rocks and earth can reach levels of 6 mSv per year in areas of the southwest of England and 8 mSv per year in parts of Finland. People living at high altitudes, such as Denver in the USA, also receive high doses of radiation because of the reduced atmospheric attenuation. There is no evidence that people living in these areas suffer any adverse health effects from exposure to these radiation doses, which are greater than the doses received by flight crew from cosmic radiation.

Relative humidity

Humidity is the concentration of water vapour in the air. It may be expressed in absolute terms either as mass per unit volume of air (g/m^3) or as a partial pressure (mmHg, torr or kilopascal). There is an upper limit of water vapour which air can hold at any temperature and when this maximum is reached the air is said to be saturated.

Relative humidity (RH) is the ratio of the actual amount of water vapour in the air to the amount that would be present if the air was saturated at the same temperature, expressed as a percentage. Saturated air at high temperatures holds more water vapour than at low temperatures, and if unsaturated air is cooled, it becomes saturated. The temperature at saturation is called the dew point and if the air is cooled below this level some of the water vapour condenses.

At an altitude of 30,000 ft, the outside air temperature is in the region of –40°C and is extremely dry, typically containing about 0.15 g/kg of moisture. For pressurised aircraft flying at these levels, the conditioned air entering the cabin has a relative humidity of <1%. Exhaled moisture from passengers and crew, together with moisture from galleys and toilets, increases the humidity but the average levels usually remain in the region of 6 to 10% which is below the

20% normally accepted as comfort level. Levels on the flight deck can be as low as 3%.

Research has shown that the maximum additional water lost from an individual during an eight-hour period in zero humidity, compared with normal day to day loss, is around 100 ml. The sensation of thirst experienced by a healthy individual in the low humidity environment is due to local drying of the pharyngeal membranes, and this itself may lead to the spurious sensation of thirst. There is no evidence that exposure to a low humidity environment itself leads to dehydration. Low humidity can cause mild subjective symptoms, such as dryness of the eyes and mucous membranes.

However, no significant effect has been shown on reaction time or other measures of psycho-motor performance, although there can be some changes in the fluid regulatory hormones. It is unlikely that low humidity has any long- or short-term ill effects, provided overall hydration is maintained by drinking adequate amounts of fluid. The low relative humidity in a passenger aircraft cabin can be thought of as a nuisance, but there is no medical evidence that it is a direct cause of adverse health effects, other than minor discomfort. This may lead to dry eye irritation, which can be alleviated by the use of moisturising eye drops, or dry skin which can be alleviated by the use of moisturising aqueous cream.

Chapter 3

Man and the Environment: The Sensory System

The senses in man are sight, sound, touch, smell and taste. Human perception utilises information from all five sources, and it has been said that one can only perceive what one can conceive.

3.1 The central and peripheral nervous system

The nervous system is the controlling and organising structure of the body, the seat of consciousness, memory and emotion. It is an information collecting system with massive storage capacity, able to relate new data to knowledge derived from past experience and thus achieve creativity. It is also highly responsive, reacting constantly to incoming stimuli by appropriate bodily movement so as to promote survival, well-being and adaptation to a constantly changing environment.

The nervous system has three main parts as shown below.

Central nervous system

This consists of the brain and spinal cord which effectively form a single organ, the spinal cord being the downward extension of the brain from the brain stem.

The brain is the processor of different sensory inputs, the origin of cognitive processes and the site of memory. It has a number of anatomically discrete areas, such as the cortex within which vision is processed and the cerebellum which is the area where balance and co-ordination are processed.

Peripheral nervous system

The nerves in this system link the various parts of the body to the central nervous system. There are 12 pairs of cranial nerves which

run out from the brain and its stem and connect them to the sense organs and muscles of the head and neck. From the spinal cord, 31 pairs of spinal nerves pass out through the gaps between the bones of the spine (vertebrae). These are composite nerves containing fibres that activate muscles plus fibres that carry sensory information. The branches of these nerves extend throughout the body to the ends of the limbs.

The autonomic nervous (vegetative) system

This is concerned with the unconscious control of functions such as digestion, heartbeat, blood pressure, body temperature and sweating. Its component nerve cells lie in a chain of linked clumps, called ganglia, parallel to the spinal cord and just outside its bony canal. It also includes a certain number of direct connections between the ganglia and the brain.

The autonomic system is divided into sympathetic and parasympathetic systems. The sympathetic system is concerned with the body's response to stressful situations (the fight or flight response) and involves the cranial, thoracic, and upper lumbar nerves. The para-sympathetic system acts on the body during sleep and involves the sacral (lower back) nerves and some cranial nerves. During periods of stress, it prolongs the body's mobilisation.

The sympathetic and para-sympathetic nervous systems potentiate their effects via the release of hormones, controlled by feedback. This is referred to as a self-regulated neuro-hormonal system.

Workings of the nervous system

The sense organs pass information to the brain via the nervous system. The sense organs are the eyes, ears, nose, the mouth taste receptors, and a range of specialised nerve endings (proprioceptive sensors) in the skin which respond to touch, pressure, pain, pin prick and temperature. The information is carried by the sensory and cranial nerves to the brain, where it is registered, stored and compared with previously stored data.

An appropriate response is facilitated by the motor nerves which cause muscles to contract or glands to secrete. Most muscles are voluntary (can be consciously controlled) but there are also many which contract involuntarily (without conscious control, or even

awareness in some cases). Involuntary control is organised by the autonomic nervous system once information has been processed by the brain.

A nerve impulse is triggered by a chemical reaction in the nerve tissue which initiates an electrical discharge along the nerve fibre. Thus transmission of a nerve impulse is an electrochemical phenomenon, and electrical activity in the brain can be measured by the electroencephalogram (EEG). Sensory organs have a threshold below which they do not respond; for example, the eyes require a minimum light level for vision and the ears cannot hear sound below a certain pressure level.

The sensory threshold is different for different sensory organs and may vary in individuals from moment to moment. This is referred to as *sensitivity* and can be influenced by many factors such as the individual's arousal or by the nature of the environment surrounding the individual at that time.

Continuing stimulation can lead to a change in sensitivity and this is known as *habituation*. A reduction in sensitivity due to habituation may lead to reduced sensory awareness. This can have implications for flight safety, e.g. reduced visual sensitivity due to an unchanging visual scene flying at high altitude above cloud.

Adaptation occurs when the sensory response is modified as a result of continuous exposure to a situation, which may lead to a change in sensitivity. Examples include night vision adaptation, when the rods in the retina of the eye become more sensitive in the continuing absence of bright light, or aural adaptation when a continuous background noise ceases to be consciously perceived.

Muscles which are normally under voluntary control may respond involuntarily and sometimes unconsciously to a stimulus; this is known as a *reflex*. Many reflex responses involve conscious awareness but they occur almost before we are aware of them.

One example is the reflex which makes an individual pull the hand away at once when it accidentally touches something very hot. The reflex is triggered by a sensory signal passing to the spinal cord, linking then to the cell bodies of the motor nerve fibres, and then passing to the various muscles causing them to contract. At the same time, pain messages pass up the spinal cord to the brain which is not involved in the reflex, except to memorise the danger situation. With forewarning, the brain can override the reflex and maintain the hand in contact with the hot source.

As well as involving reflexes, biological control systems employ the principle of 'feedback' rather like the governors on a steam engine. When a muscular movement is made, the motor centres in the central nervous system send impulses via the motor nerve to the muscles which contract in the appropriate sequence and in such a manner that the appropriate degree or strength of contraction is attained. The stronger the contraction required, the greater is the number of nerve fibres brought into play. Once the desired movement or action has been achieved, the sensory system feeds this back to the brain which then turns off the motor impulses.

Neuro-hormonal feedback occurs in a similar way. For example, insulin is produced by the pancreas gland to control the level of carbohydrate in the blood within precise concentration limits. Immediately after a meal, insulin is released to lower the high carbohydrate levels and once the appropriate level is reached, feedback to the pancreas turns off the production of insulin.

3.2 Vision

Of the five senses, vision is used and relied on most. However, it has limitations with which aircrew must be familiar.

Functional anatomy of the eye

The eye is in many ways like a camera. Both have a shutter, diaphragm, lens and method of focusing within a container – in the eye this container is the eyeball.

The eyeball is moved by surrounding muscles and the lacrimal gland produces fluid (tears) to moisten the cornea. The eyelids act as protective shutters for the eyeballs.

Light passes through the transparent cornea, where most refraction (70 to 80%) occurs, before reaching the lens (Figure 3.1). The pupil grows larger in conditions of reduced light and smaller when the light increases, thus ensuring the correct amount of light falls on the retina. The lens focuses the light on the retina.

Imperfect refraction of the light rays passing through the cornea and lens may lead to difficulty in focusing the image on the retina, causing a reduction in visual acuity. An increase in refractive power of the eye causes the image to be focused in front of the retina

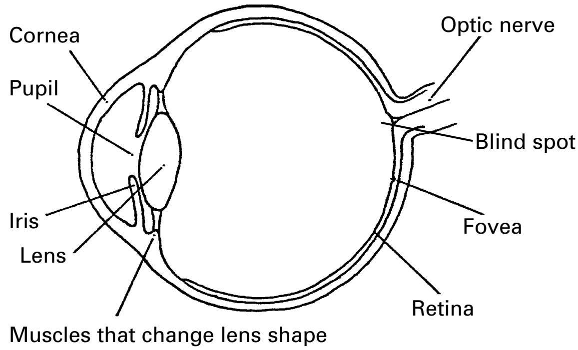

Fig. 3.1 The eye (left eye seen from above).

(myopia), whereas a reduction in refractive power focuses the image beyond the retina (hypermetropia). Refractive errors can be corrected with suitable lenses.

Visual acuity is the capacity of the eye to resolve detail. To obtain the highest resolution, the target being observed must be focused on to the fovea. Visual acuity may be degraded by the shape of the eyeball, age, fatigue, alcohol, hypoxia and smoking. In an individual with normal eyesight, acuity at the fovea is 6/6 and the target subtends an angle on the retina of 5 minutes of arc.

The *fovea* is the region on the retina composed only of cone nerve endings, which are the visual nerve endings providing greatest acuity. Acuity diminishes rapidly after 2 to 3° from the centre of the fovea. At 5°, acuity has halved to 6/12, and at 25° it has decreased by a tenth to 6/60.

Visual field is the target area from which each retina can detect visual input. Anything lying outside the visual field of a retina will not be detected by that eye. Reduction in the visual field can be the first sign of the onset of certain pathological conditions, such as glaucoma (a rise in pressure in the anterior chamber of the eye).

Central vision is the perception by the brain from nerve inputs originating in the fovea. It gives best visual acuity.

Peripheral vision is the perception by the brain from nerve inputs originating from the areas of the retina away from the fovea. It is used for detecting movement.

Accommodation is the ability of the eye to alter its focal length. The speed and range of accommodation reduces with age, particularly in low light levels.

The *iris* is the light adaption mechanism which caters for levels of illumination. The pupil grows larger in conditions of reduced light and smaller when the light level increases, ensuring the optimum amount of light falls on the retina. The adjustment range of the iris is 5:1.

Physiology of vision

The retina has special receptor cells which convert light energy into nerve impulses. These impulses pass to other cells in the retina before travelling along the optic nerve to the optic chiasma, which is the intersection of the two nerve tracts leading to either side of the brain. Information from both eyes is interpreted in the area of the brain known as the visual cortex. There are two types of nerve endings in the retina, cones and rods, differentiated by their construction and function.

The *cones* are located in the centre of the retina (fovea) and are used for day or high intensity light vision. There are a number of types of cone and they are involved with central vision to detect detail, perceive colour and identify far-away objects. They function poorly in dim light.

Some male individuals are deficient in the ability to perceive *colour*. This is due to a congenital absence of the cones sensitive to particular colours and is known as colour blindness. There are different degrees of colour blindness, the commonest affecting perception at the red–green end of the visual light spectrum, but it has no effect on visual acuity. Colour perception can be important for identifying navigation and signal lights (particularly at night), interpreting maps and charts, and interpreting electronic flight instrument displays. Perception of red and orange colour predominates in bright light whereas colours from the violet end of the spectrum predominate when light is dim. Colour becomes less distinct with distance.

The *rods* are located in the periphery of the retina, an area that is about 10,000 times more sensitive to light than the fovea. The rods are used in low light intensity by looking slightly to one side of objects rather than directly at them. Thus peripheral vision utilises the rods rather than the central cones.

This effect can be demonstrated at night by counting a group of faint lights in the distance when looking directly at them. Then by looking some 10° to one side it will be possible to see more lights.

A blind spot occurs in the central vision where the optic nerve enters the eye. This can be demonstrated by covering the left eye and using the right eye to focus on the image of the aeroplane in Figure 3.2.

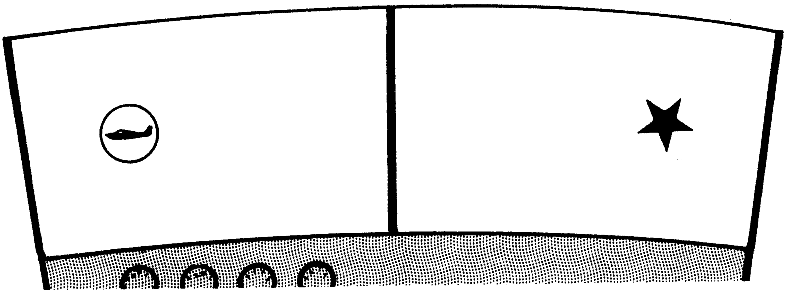

Fig. 3.2 Demonstration of visual blind spot.

Move the page slowly closer to the face and at some point the black star on the right will disappear as the image falls upon the blind spot. Although this does not occur when both eyes are used, the overlap of the two visual fields is imperfect because of the intrusion of facial features such as the nose.

A further point to remember is that some people who have perfect day vision may be myopic (near sighted) at night. Night myopia is little recognised, but can present a significant hazard because of the false confidence instilled by having good visual acuity by day. Night myopia occurs because of the way the eye differentially focuses the frequencies of different colours. Red and orange predominate by day and a lens, whether natural or artificial, which is easily capable of focusing these wavelengths will be less effective when focusing the colours from the violet end of the spectrum which prevail at night. In low light conditions, the lens of the eye has sufficient elasticity to focus the light from near objects but cannot focus properly on objects further away (near sightedness or myopia).

This can be compounded by the effects of increasing age. Ageing causes the elasticity of the lens to diminish, a condition known as presbyopia. In the case of a pilot who is already myopic and wears corrective spectacles, one of the effects of increasing age is that the daytime correction may be inadequate by night.

Another effect of ageing is that the speed of accommodation

reduces, especially in poor light. It is also worth remembering that mild hypoxia can impair visual acuity, which is particularly important during night flying.

The visual field – scanning techniques

Scanning the sky for other aircraft is obviously important in avoiding mid-air collisions, particularly when flying under visual flight rules. Less than 10% of mid-air collisions occur between aircraft approaching head-on. Therefore, it is essential to develop and practise a scanning technique that allows the efficient monitoring of the surrounding air space as well as the cockpit instrumentation.

A large aircraft such as a 747 can be seen quite easily when a few hundred metres away, but only when you are looking at it. Pilot workload will influence the time available for visual scanning and even when two pilots are employed, there will be moments when no-one is looking outside. Lookout often becomes what is left of 'look in' time, so it is essential to arrange cockpit workload in a sensible manner to allow maximum time for looking out and scanning the sky.

Another point is the speed of today's jet aircraft, usually in the order of 500 knots for military aircraft and 250 knots in the lower levels for civil airliners. If the speed of closure between two aircraft is considered, it takes little calculation to appreciate that an aircraft which is 10 km away on an opposing heading will take but a few seconds to occupy your piece of airspace. For example, assuming a closure speed of 600 knots (which is 1 nm in 6 seconds) and a visibility of 6 nm, from the moment it is possible to spot the other aircraft there will be only 36 seconds before the aircraft meet. This might appear to give time to take avoiding action, but it is rare that an aircraft is spotted at the first possible moment. In fact trials have shown that the time interval between spotting another aircraft and taking avoiding action is around ten seconds. There are many reasons for this, including cockpit workload, position of the opposing aircraft during the scan period and its contrast with the surrounding environment. The time from visual input to recognition is approximately one second, and is referred to as the visual perception cascade. Figure 3.3 shows a graphical representation of the changing size of an aircraft closing at 500 knots.

It is the relative movement of the two aircraft which is the most

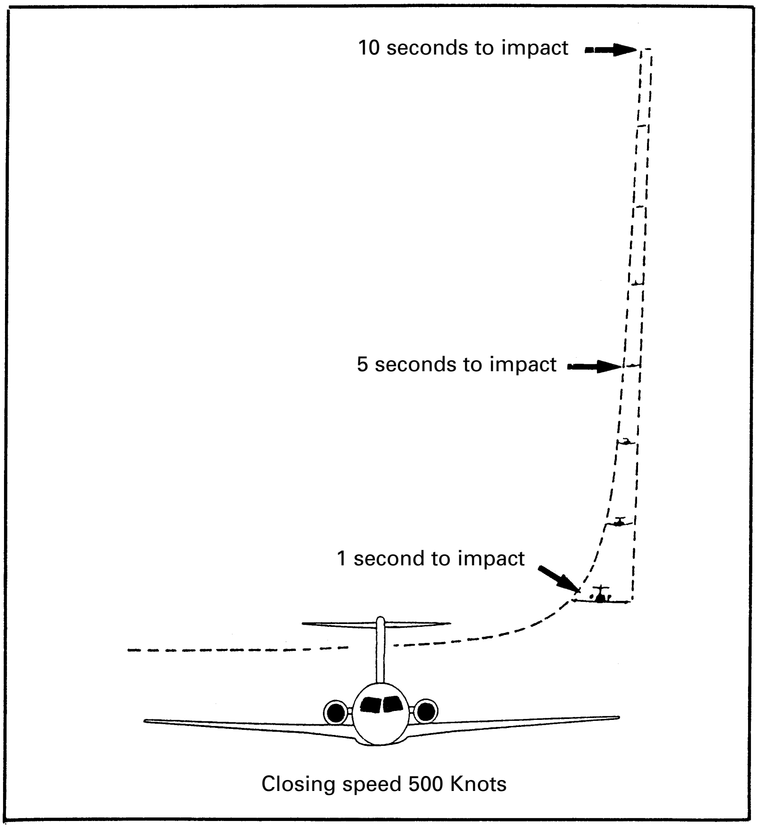

Fig. 3.3 The change in perceived size of an aircraft closing at 500 knots.

important aspect in visibility. Aircraft which move across the visual field will stimulate more of the peripheral nerve endings in the eyes and so are noticed sooner, but an aircraft which has relative movement to the observer is not usually a collision risk. It is when two aircraft are on constant headings, speeds and altitudes and are going to collide that there will be no relative movement between them and they will appear stationary from the cockpits. In this situation one of the most important cues (movement) is missing at a time when the greatest threat is being posed. Figure 3.4 illustrates this constant bearing situation.

When above cloud, an aircraft approaching or converging from a distance which appears to be at the same altitude as the observer will pass below.

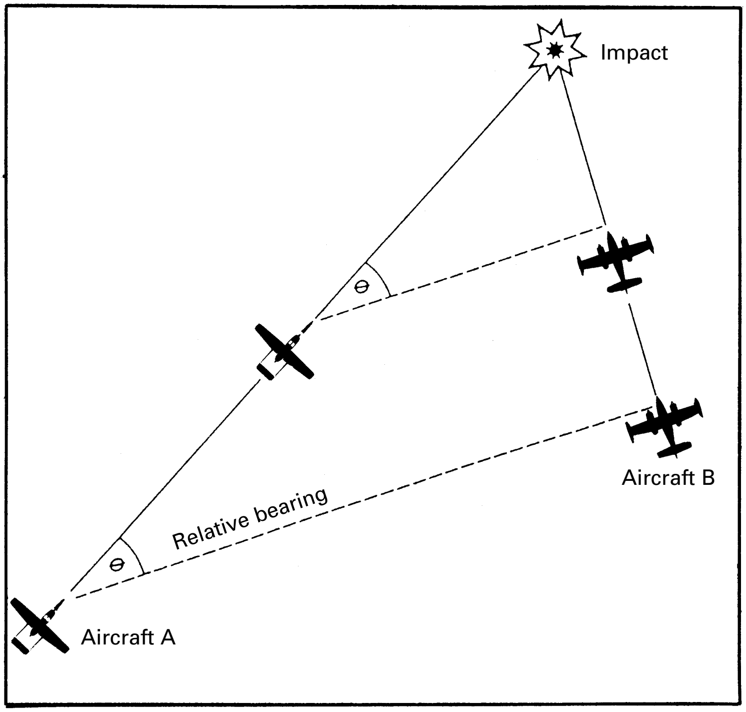

Fig. 3.4 The constant relative bearing of two aircraft on collision course.

The best chance of avoiding mid-air collision is to maintain a constantly updated situational awareness of what is going on in the sky around you. Knowing where to look during the various phases of flight will considerably improve lookout. This particularly applies when entering an aerodrome traffic zone or flying close to ground-based navigation aids where one expects a greater concentration of traffic. In addition, the information available from radio calls made by other aircraft should be intelligently used to assess when extra vigilance is required and which areas of the sky to search.

When searching for a target, the eye cannot be moved continuously and smoothly. It moves in jerks with rests between them, the movement being known as saccades. The external world is sampled only during the rest phase, although the eye and brain integrate the information acquired in order to provide smooth perception of events. An eye movement/rest cycle (saccade cycle) takes about one-third of a second, and this limits the detail which can be examined from the external world. The probability of

detecting a conflicting aircraft can be maximised by making as many eye movements as possible and minimising the duration of the rests.

When searching the sky for other aircraft you should be aware of a condition known as 'empty field myopia'. This may occur when looking out of the cockpit at an empty sky. Because there is nothing at infinity on which to focus, the eye focuses at a point approximately between one and two metres away. This is aggravated by the windscreen frame and other parts of the aircraft structure which attract the focusing point in from infinity. As a result the eyes appear to search the surrounding area, but are in fact focused at a very close distance, so aircraft in the surrounding airspace may not be spotted. This can be alleviated to some extent by focusing on ground objects at frequent intervals, or in low visibility to focus on the wing tips from time to time. Having said that, most near miss incidents and mid-air collisions occur in conditions of good visibility and by day.

When developing a technique for effective visual scanning, it is necessary to perform a series of short, regularly spaced eye movements which bring successive areas of sky into the central (foveal) visual field. Scan from right to left or left to right, beginning a scan at the top of the visual field in front of you and then moving the eyes inward towards the bottom. Each movement should be 10° at the most, and each area should be observed for at least 1 second but not longer than 2 to 3 seconds. The alternating movement and stopping of the eyes during the scan is known as the saccade/rest cycle.

In low visibility, avoid looking directly at an object for more than 2 to 3 seconds (because it will bleach out). Instead, use the off-centre viewing that consists of search movements of the eyes (10° above, below, or to either side) to locate an object, and small eye movements to keep the object in sight. Switching the eyes from one offset point to another every 2 to 3 seconds will enable the object to be detected in the peripheral field of vision.

Remember to move the body as well as the head to see around physical obstructions such as door and window posts.

Binocular and monocular vision

The use of two eyes (binocular vision) is important in *depth perception*. This is the function of judging distance, both horizontal and vertical. However, binocular cues are only of importance when

viewing objects close at hand. At greater distances, depth is perceived from information on relative object size, texture and brightness (monocular cues).

Depth perception monocular cues

- *Size of the retinal image* – comparison of the perceived object with size known from past experience
- *Motion parallax* – near objects appear to move against the observer's motion, whereas distant objects move in the same direction as the observer's motion
- *Obscuration* – nearer objects appear to cover distant objects (also known as interposition)
- *Texture* – visual detail of colour and texture lost at increasing distance
- *Atmospheric perspective* – distant objects appear more blue and hazy than near objects
- *Linear perspective* – parallel lines converge at a distance
- *Apparent foreshortening* – a circle appears as an ellipse when viewed at an angle.

Depth perception binocular cues

Generally used only for distances up to 200 metres.

- *Convergence* – the amount that the axes of the eyes converge to bring a visual target on to each fovea
- *Stereopsis* – the fusion of signals from slightly disparate retinal points, measured in seconds of arc of disparity
- *Accommodation* – if the eye observes a close object, the lens is thickened and the pupil becomes larger, while to focus on a more distant target, the lens flattens and the pupil becomes smaller.

An individual who has had only one functioning eye from childhood develops the ability to compensate. However, if an eye is lost at a later age it may take several months to develop adaptation to monocularity. During this adaptation period, an individual may experience hazy vision and occasional loss of balance, due to conflicting sensory information compared with past experience. A medical flight test is usually required to determine whether a person with monocular vision is acceptable on safety grounds.

Night vision

Night vision is derived from the rods in the retina and these are very sensitive to hypoxia, either as a result of low oxygen concentration in the ambient air or the presence of carbon monoxide from tobacco smoking or exhaust fumes. Night vision is also affected by age and alcohol.

Dark adaptation is the process by which the eyes adapt for optimal night visual acuity under conditions of low ambient illumination. The eyes require between 30 and 45 minutes to fully adapt to minimal lighting conditions. The lower the starting level of illumination, the more rapidly complete dark adaptation is achieved. To minimise the time necessary to achieve complete dark adaptation and to avoid losing it:

- avoid inhaling carbon monoxide from smoking or exhaust fumes
- adjust instrument and cockpit lighting to a level as low as possible
- avoid exposure to bright lights
- use supplemental oxygen when flying at night above 5,000 ft.

If dark adapted eyes are exposed to a bright light source, e.g. landing lights, for a period in excess of one second, night vision is temporarily impaired. Exposure to aircraft anti-collision lights does not impair night vision adaptation because the intermittent flashes have a very short duration (< 1 second).

In an attempt to preserve night adaptation, red light used to be used for cockpit illumination. However, it was found that with so many other sources of ambient light it made little practical difference. Also, the use of red light can obscure detail from topographical charts and airfield approach plates. The current standard is for white lighting, unless compatibility is required with night vision goggles when blue lighting is used. However, blue lighting leads to similar problems of interference with colour coded information on charts and plates. Thus cockpits so equipped have the facility to switch back to white lighting when night vision goggles are not in use.

3.3 Hearing

Functional anatomy of the ear

The ear consists of three parts, the outer ear, the middle ear and the inner ear (Figure 3.5).

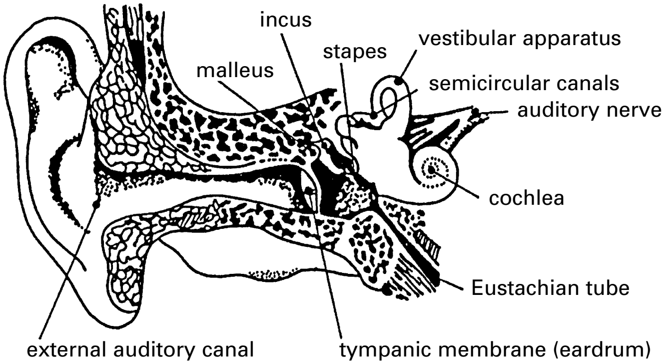

Fig. 3.5 The ear.

The *outer ear* is composed of the ear flap (pinna) and the ear canal.

The *middle ear* contains the eardrum, the auditory ossicles (sound conducting bones) and the Eustachian (pharyngo-tympanic) tube.

The *inner ear* contains the cochlea (organ of hearing) and the balance mechanism.

The ear pinna collects sounds and directs them along the ear canal to the eardrum. Sounds, which are small fluctuations in air pressure, cause the drum to vibrate. For the drum to be sensitive to sound, the air in the middle ear must be at the same pressure as the air in the outer ear and this pressure is equalised by the Eustachian tube which connects the ear with the back of the throat. When climbing or descending in an aeroplane, a ‘popping’ sensation may be felt in the ears and is the result of uneven pressures being equalised between the outer and middle ear.

Sound pressure waves vibrate the eardrum (tympanic membrane) and these small vibrations are amplified by the three bones forming the ossicular chain. The third bone is shaped like a stirrup and this transmits the sound waves to the fluid (endolymph) contained within the cochlea. The sound pressure waves which move through

the endolymph displace sensory hairs contained within the hearing organ (organ of Corti). Signals are transmitted to the brain via the auditory nerve and are perceived as sound. Different sound frequencies are detected by different groups of sensory hairs which explains why some forms of deafness lead to loss of the ability to perceive certain sound frequencies but not others.

The normal human ear can hear sound in the range of approximately 20 to 20,000 Hz. Normal conversation frequencies lie between 500 and 3,000 Hz, with the vowel frequencies between 500 and 2,000 Hz, and the consonants between 1,000 and 2,000 Hz.

Flight related hazards to hearing

It has been seen that hearing basically depends on two mechanisms. The first is the conduction system consisting of the eardrum and the bony ossicles to transmit the vibration and the second is the transducer system, the cochlea. Deafness affecting the first system is known as *conductive deafness*, whereas deafness affecting the cochlea or the nerve pathway connecting the cochlea to the brain is known as *sensori-neural deafness*.

Conductive deafness may arise in childhood from damage to the middle ear due to infection or trauma. Temporary conductive deafness can result from damage to the tympanic membrane, such as a perforation which can occur as a result of flying when suffering from an upper respiratory tract infection. Conductive deafness is often treatable with medication or surgery.

Sensori-neural deafness arising from damage to the cochlea or the nerve conduction system is usually irreversible. The hearing organ within the cochlea responds to vibrations but may be damaged by over stimulation in the form of loud and prolonged noise. Noise induced hearing loss (NIHL) may be temporary at first, but excessive and continuing exposure will lead to permanent damage and hearing loss.

Noise levels are measured using the decibel scale, which is a logarithmic scale relating to an arbitrary normal value of 0 dB. 0 dB is the sound pressure level experienced in a soundproofed environment such as a recording studio; 50 dB is the sound level experienced in the average office; 70 dB would be experienced during normal conversation and 100–120 dB would be the sound of a large jet aircraft taking off. Hearing may be damaged when exposed

to noise energy in excess of 90 dB for prolonged periods. The damage is not only related to the loudness of the noise but also to the length of exposure and the frequency of the sound, i.e. it is the total noise energy which matters. Thus 90 dB experienced for 8 hours will be as damaging to the ear as 103 dB for 30 minutes.

The noise levels in the cockpit of some light aeroplanes can be high, and efficient noise cancelling headsets should be worn routinely.

One source of hazard to hearing in the cockpit is the use of excessive volume when listening through the radio headset. Although the noise level in most jet aircraft flight decks is below that which would cause hearing damage, the practice of leaving one ear uncovered while listening to radio telephone communications through the other ear can be hazardous to hearing. To enable the radio transmissions to be intelligible, it is necessary to increase the volume in the headset sufficiently to overcome the ambient noise being detected by the uncovered ear. This can lead to sound levels in the covered ear in excess of 90 dB which can cause hearing damage if the time of exposure is prolonged.

The airport ramp or apron area is noisy. In some cases, the noise on the ramp may well exceed 90 dB and hearing protection should be worn when performing pre-flight external checks.

One of the effects of ageing is a reduction in the ability to hear high frequency sounds. This is known as presbycusis and is an irreversible part of the normal ageing process.

Effects of altitude change

Consistent with Boyle's law, the air in the cavity of the middle ear expands and contracts with changes in atmospheric pressure. During a change in altitude if the pressure in the ear is not readily equalised with the outside pressure, the drum is distended leading to inflammation with pain and temporary deafness. The Eustachian tube leads from middle ear to the back of the throat, so the middle ear communicates with the outside air and in normal conditions any difference between the middle ear and the outside atmosphere is equalised. The tube normally remains in a collapsed state, but it is briefly opened by swallowing or yawning.

When the air in the middle ear expands, as for example during a climb, a small bubble of air is forced out through the Eustachian

tube at frequent intervals. Normally no difficulty should be experienced during the climb to higher altitudes because the pressure equalisation occurs automatically. During descent the situation is reversed. As the surrounding air pressure increases, the middle ear, which has accommodated to the reduced pressure at altitude, is at a lower pressure than the external ear canal. Consequently, the increase in pressure of the outside air forces the eardrum to bulge inward. This is much more difficult to relieve because air must now go back up the Eustachian tube to equalise the pressure between the inner ear and the outside atmosphere. The lower pressure in the Eustachian tube tends to collapse the tube rather than inflate it. This produces a sense of fullness, discomfort and even pain and temporary deafness.

Normally, ventilation of the middle ear during descent can be achieved by frequent swallowing or yawning, producing a contraction of the small throat muscles which briefly open up the Eustachian tube. When swallowing or yawning has no effect, the Valsalva manoeuvre can be performed. To do this, the mouth is closed, the nostrils pinched shut and then one should blow slowly and gently to build up pressure in the mouth and nose. It is important to ventilate the ears at frequent intervals during the descent, and if the ventilation becomes difficult the rate of descent should be decreased or even stopped at intervals to allow more time for the pressure to equalise.

Flying while suffering from a cold, catarrh or other upper respiratory infection is inadvisable because the tissue around the nasal end of the Eustachian tube will probably be swollen. This can cause the small orifice of the tube to be restricted or even closed, with resulting difficulty in equalising the pressure. If the pressure cannot be equalised, then there will be a risk of the eardrum becoming perforated; a perforation usually heals within six weeks but occasionally surgical intervention is necessary.

3.4 Equilibrium

Functional anatomy of the vestibular system

In addition to being the organ of hearing, the ear also contains the organ of balance. This is the vestibular apparatus which consists of

the semi-circular canals plus the otoliths contained within the utricle and saccule of the inner ear. The three semi-circular canals are interconnected and contain fluid known as endolymph (Figure 3.6). The semi-circular canals form a motion sensing system and are arranged approximately at right angles to each other in the roll, pitch and yaw axes. Their function is to assist in the maintenance of balance and to stabilise the eyes during walking or running on the ground.

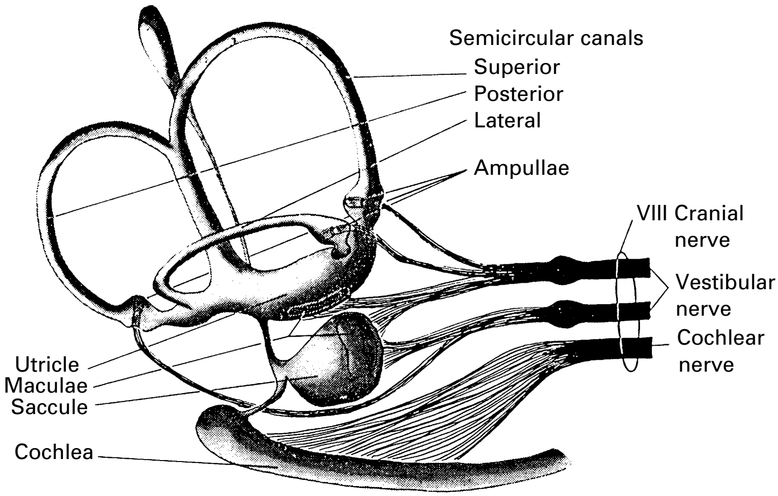

Fig. 3.6 The semi-circular canals of the vestibular system.

Angular acceleration is detected through small sensory hairs that project into a cupula located in each canal. When the head begins to turn (angular acceleration), or speeds up, slows down or stops turning, the sensory hairs in the canal in the axis of the turn are temporarily deflected due to the motion of the fluid lagging behind the motion of the canal wall. Nerve impulses are sent to the brain and a sensation of turning is felt. A sensory organ for gravity and linear acceleration (otolith) is located in the bottom and side of a common sac. It consists of small sensory hairs that project upward into a gelatinous substance containing chalk-like crystals. The apparent weight borne by these sensory hairs changes with every head movement up, down, left, right, forward and backward, thus causing the sensation of tilting the head or body. This equilibrium has evolved for mankind on the surface of the earth. However, once

an individual becomes airborne, misleading messages can be received causing a state of disorientation.

Motion sickness

Motion sickness is a normal human response to unfamiliar motion and affects different individuals in different ways. Some people are totally unaffected by motion, whereas others suffer severe nausea and vomiting at the mere mention of the words 'cross-channel ferry' or 'Cessna 150'! Most people lie somewhere between the two.

Causes

Sickness is a fairly common problem in early flying training and in passengers unfamiliar with flight in light aeroplanes. The cause is complex and not fully understood, but there is no doubt that the vestibular apparatus in the inner ear plays an essential role.

Information on orientation and motion within the spatial environment is provided by the eyes, inner ear receptors and nerve endings in the muscles and joints. As we grow up we learn to associate specific patterns of sensory information with motion in relation to what we are seeing.

Motion in flight, at sea, in a car or in a space shuttle generates patterns of sensory input which conflict with those patterns based on terrestrial experience. The brain is upset by this conflict and motion sickness results. The strength of the signals generated by the vestibular system appear stronger in some people than in others, i.e. some have more sensitive vestibular systems.

Anxiety and hyperventilation also play an important part in the development of motion sickness. When a person is anxious and tense the whole nervous system becomes extra sensitive, and if the vestibular system is already sensitive the anxiety can take it above the critical level. Hyperventilation acts in a similar way, by raising the individual's arousal level (or possibly the increased arousal leads to the hyperventilation). This again increases the sensitivity of the vestibular system, making motion sickness more likely in a susceptible individual.

The after-effects of alcohol may play an important role in the development of motion sickness. It is well accepted that aircrew should not fly within at least 12 hours of drinking alcohol. However, it is often not realised that the effects on the vestibular system of

even small quantities of alcohol may be detected for several days afterwards.

Alcohol diffuses from the bloodstream into the fluid (endolymph) in the semi-circular canals. Because it is less dense than water the alcohol does not become evenly distributed within the endolymph, but creates a light spot which causes the fluid to move within the semi-circular canal as if the head was turning. This increases the sensitivity of the canal, leading to the well-known sensation of the head spinning. However, even following the removal of alcohol from the bloodstream, the increased sensitivity of the canals remains for some time.

Symptoms and signs

The earliest symptom of motion sickness is usually unease in the stomach. Hyperventilation and 'air hunger' is common. The victim's face is usually pale and he or she begins to sweat. This is followed by increased salivation, a feeling of body warmth, light-headedness and, occasionally, depression and apathy. By this stage vomiting is usually not far away, although some people remain severely nauseated for long periods and do not obtain the transitory relief of vomiting.

Many people find motion sickness severely debilitating and have great difficulty functioning efficiently and safely. Other people find that once they have vomited they feel well again and carry on with the task in hand with no problems.

Prevention

The human body has a remarkable ability to adapt to changes in environment or to new sensations. With continued exposure to a provocative environment, such as flying in a light aeroplane, it seems that the new sensory patterns become accepted as the norm by the brain and motion sickness happens less easily. However, this requires regular exposure to the environment, which explains why some experienced aircrew suffer from nausea or sickness on their first flight after a break away from flying. This does not happen in all cases, and these individuals are said to show good retention of adaptation.

To help prevent motion sickness, keep stimulation of the semi-circular canals to a minimum; this means that head movements

should be limited, within the requirements of maintaining adequate lookout. If an individual is known to be susceptible to motion sickness, this advice should be followed *before* the onset of symptoms. The same applies to passengers unused to flying.

Vision plays a strong part and it is therefore good practice to fix the gaze on a stable distant horizon. If there is no horizon, e.g. in cloud, it often helps to rest the head on the back of the seat and keep the eyes closed (assuming someone else is flying the aeroplane!). Bending the head forward to read induces motion sickness in the susceptible individual and it may help to bring maps and checklists up level with the coaming. This has the added bonus of improving lookout. Passengers should be discouraged from reading in flight, and it helps to keep them occupied by drawing their attention outside, to things at a distance. Be on your guard for impending air sickness when the passenger goes quiet, looks pale and begins to sweat and hyperventilate.

There is much conflicting advice on whether one should eat before a flight. In fact it makes little difference. The origin of motion sickness is the vestibular system not the stomach, so the best advice is to eat as normal and maintain a good blood sugar level. Similarly, smells and heat are not causes. However if one is starting to feel unwell, unpleasant smells and a stuffy atmosphere become more intrusive and contribute to the feeling of malaise.

There are many drugs available to counteract motion sickness. Some are only available on prescription, but others can be bought over the counter. All these drugs, however, have side-effects which can affect flying performance, including drowsiness, increased reaction time, poor muscular co-ordination and a reduced rate of information processing. Different people react in different ways, but the drugs affect everybody to some extent. They are suitable for use by passengers and in certain circumstances may be used by student pilots when flying dual with an instructor. But *these drugs must not be taken by pilots flying solo or as captain.*

Of the drugs available the most effective is hyoscine (sold in many countries as Kwells). Cinnarizine (sold as Stugeron) is effective for longer but must be taken at least 30 minutes before getting airborne. Both these drugs have the side-effects mentioned above.

Other preventative methods which have been suggested include wrist bands which apply pressure at the acupuncture point and extract of ginger taken by mouth. Anecdotal evidence suggests that

they work, but scientific research has so far failed to prove it. However, they do no harm and might be worth a try.

As already mentioned, one of the best preventative measures is to avoid alcohol and in the case of people who have a tendency to suffer from motion sickness this avoidance should be for at least 24 hours prior to flying.

3.5 Integration of sensory inputs

A stimulus must reach the sensory threshold before being registered by a particular sense.

Orientation

Information from the body's sense organs – the eyes, the hearing and vestibular organs of the inner ear and the proprioceptive nerve endings in the skin, muscles and joints – is passed to the brain. The information is processed to determine orientation, i.e. the position of the body in space.

The human body evolved in its natural terrestrial environment. However, flying takes the body away from its natural environment and conflicting information from the individual sensory organs may lead to disorientation, as a result of mismatch in sensory input and central processing.

The most important information comes from well-defined external visual cues, and if these are present, disorientation is uncommon. However, when a pilot attempts to fly without a visible horizon, such as in cloud, fog, precipitation or darkness, disorientation will occur unless attention is turned to the aircraft instruments.

Tests have shown that without adequate visual cues, control of the aircraft is lost within about 60 seconds of vision being lost in straight and level flight, and in an even shorter time if the aircraft is in a turn.

Sensory illusions and spatial disorientation

An illusion can be defined as a false impression or unreal vision formed when sensory information is misinterpreted by the brain. Spatial disorientation is a false perception of orientation of the

aircraft, with respect to spatial references such as flight path and altitude, or reference to objects with respect to expected shape or size. These may occur when the sensory organs send conflicting information to the brain.

In the absence of powerful visual information, complex and interactive forces can create specific illusions. In the absence of external visual reference, e.g. flying in cloud, conditions of poor visibility or at night, the conflicting sensory information can be overcome by reference to the flight instruments. The information displayed has to be interpreted and integrated from the two-dimensional displays to give situational awareness in the four dimensions of flight. This is a skill which has to be learned and practised.

Vestibular illusions

Illusion of level flight (the leans) (oculogyral illusion)

In straight and level flight the fluid in the semi-circular canals of the ear is stationary and the hair detectors are not deflected. Any movement of the head, for example as a result of aircraft roll or pitch, will cause a reaction in the appropriate pair of canals and this is perceived as movement in the appropriate direction. The signal to the brain is the result of the sensory hairs being deflected by the relative movement of the fluid, but continuing the motion at a steady rate will allow the fluid to catch up with the aircraft and the hairs will revert to their original upright position.

This leads to a false perception that the aircraft is once again flying straight and level, a condition referred to as 'the leans'. If the attitude cannot be confirmed visually the pilot will assume the aircraft is level, but as the aircraft is continuing to turn there will be a tendency for the nose to lower, resulting in increased air speed. If the pilot now eases back on the elevator control to counter the increase in air speed, the turn will tend to steepen and the aircraft will descend. The result is a spiral dive.

The illusion of turning in the opposite direction (somatogyral illusion)

Another illusion can occur when recovering to level flight after a turn. During the turn the fluid in the canal has stopped moving as

a steady state is achieved. As the wings are levelled, the rolling motion stimulates motion of the fluid in the appropriate semi-circular canals and the fluid continues to move after the canal itself has come to rest. This leads to a sensation of turning in the opposite direction, known as the somatogyral illusion. The pilot will therefore tend to bank the aircraft away from the falsely perceived turn.

Illusion of turning in a different axis

An abrupt head movement at a rate of 3° per second or more during a prolonged constant rate turn may set in motion the fluid in more than one pair of semi-circular canals, causing a strong sense of turning or accelerating in a different axis. This can lead to serious disorientation and is one form of the so-called Coriolis effect.

The Coriolis effect is the illusion produced by the cross-coupled response arising from the stimulation of the semi-circular canals by the interaction of angular motion in two planes, the endolymph in the two canals being subjected to what is initially a very fast angular acceleration. The Coriolis or deviation force refers to the force exerted on a fluid subjected to rotation, and is used to explain the behaviour of the atmosphere near to the earth's surface. The mathematics are not necessary for an understanding of the cross-coupled endolymph response.

Illusion of tumbling backwards (somatogravic illusion)

An abrupt change from climbing to level flight can cause excessive stimulation of the otolith which is the sensory organ for gravity and linear acceleration. This leads to the illusion of tumbling backwards, known as the 'somatogravic illusion', causing the pilot to move the elevator control forward to lower the nose. The result is to intensify the original false perception with respect to gravity.

Illusion of climbing

In a correctly balanced turn the acceleration tends to push the body into the aircraft seat, such as happens when an aircraft is being pulled into a climb or pulled out from a dive. If no visual reference is available this gravitational force may be interpreted as entering a climb and the pilot may react by moving the elevator control forward.

Illusion of diving

The positive G force perceived during a banked turn will be reduced when recovering to level flight. This reduction may be interpreted by the pilot as entering a dive and may lead to application of back pressure on the elevator control leading to a reduction in air speed.

Disorientation when rotating

Severe disorientation and vertigo can occur if the aircraft is rolling and the pilot moves his or her head out of the plane of rotation; two sets of semi-circular canals are stimulated leading to the Coriolis effect. A harsh pull out of a dive while rolling will produce the same effect, typically when pulling out from a dive following a spin, before the rotation of the fluid in the semi-circular canal has ceased.

If rotary motion occurs for a short period, e.g. during a spin, when it stops there will be a sensation of rotation in the opposite direction, due to the continuing rotation of the fluid. In the absence of good visual cues, it is possible for the pilot to respond to this false illusion by putting the aircraft into a spin in the opposite direction.

Vertigo

Vertigo is an illusory sensation of turning, although the term is often applied by pilots to any form of spatial disorientation. True vertigo is the ultimate sensation of spatial disorientation, in which the individual or his or her surroundings appear to whirl dizzily. It may be accompanied by nausea or vomiting and is a result of disturbance in the vestibular apparatus. It can be due to disease, in which case it is long lasting, but when it occurs in flight it is usually temporary lasting but a few seconds.

Visual illusions

Impulses from the sensory organs of the eye, the rods and cones in the retina, are conducted along the optic nerve to the brain for interpretation. The eye is very reliable for orientation as long as adequate reference points are available. However, in flight, objects seen from the air often look quite different from when seen on the ground thus causing difficulty in interpreting visual cues. The problems are compounded in conditions of poor visibility and visual illusions can lead to spatial disorientation or to landing errors.

Oculogravic illusions

The oculogravic illusion can be considered as the visual component of the somatogravic illusion described above. When an aircraft accelerates and there is a backward rotation of the resultant force vector, the pilot may experience an illusion of pitch up. This may be accompanied by an apparent upward movement and displacement of objects, such as a line of lights, within the visual field.

Auto-kinesis

In the dark a static light will appear to move when stared at for several seconds. The apparent movement will increase if the light source is allowed to become the prime focus of attention. To avoid the effects of this visual illusion, when flying at night it is important to shift the gaze so as not to stare at a single light source.

Illusion of level flight (false horizon)

In the absence of a clearly defined horizon, the pilot may mistakenly choose another line as a reference and, for example, may fly parallel to a sloping cloud bank instead of the earth's surface.

Approach and landing errors

The visual approach and landing of an aircraft requires the pilot to perceive and respond to a number of visual cues. When flying a 3° approach, the angle between the horizon and the visual impact point on the runway is also 3°. Thus the approach is flown by the pilot using suitable control inputs to maintain a constant angle subtended at the horizon. When flying a large aircraft, the touchdown point will be short of the visual aiming point, and account needs to be taken of this when selecting the visual aiming point on the runway. The flow of visual texture in the peripheral visual field assists final judgement of height and speed.

Surface feature and atmospheric conditions can create illusions of incorrect height and distance from the runway threshold. Landing errors from these illusions can be avoided by anticipating them during approach and using all available landing aids such as approach angle guidance lights.

Ground lighting illusions

Lights along a straight path such as a road, and even lights on

moving vehicles, can be mistaken for runway or approach lights. Bright runway and approach landing systems, especially where few lights illuminate the surrounding terrain, may create the illusion of there being less distance to the runway threshold. Flying over terrain which has few lights to provide height cues may lead to a lower than normal approach being flown.

Atmospheric illusions

Atmospheric haze, mist or fog may lead to refraction of light. This can create an illusion of greater height or greater distance from the runway. When penetrating mist or fog, an illusion of pitching up can occur leading to the approach being steepened abruptly.

Rain on the windscreen may also lead to refraction of light, creating an illusion of greater height or distance from the runway. This can lead the pilot to make a shallower than normal approach. In addition, rain on the windscreen can give a blooming effect to the perception of runway lights. This gives the impression that the approach is faster and the runway is closer than it actually is.

Runway and terrain slope illusion

An upsloping runway or terrain, or both, can create the illusion that the aircraft is at a higher altitude than it actually is and the runway looks shorter. This can lead to a lower than normal approach being flown. The runway or approach terrain which slopes down can have the opposite effect. This is shown in Figure 3.7.

Runway width illusion

When approaching a runway that is narrower than usual, it may appear that the aircraft is higher than it actually is. This can lead to a low approach being flown. Conversely runways significantly wider than those normally used will give a pilot the impression of being lower than normal, increasing the risk of levelling out high and landing well beyond the runway threshold. This is shown in Figure 3.8.

Featureless terrain (black hole)

An absence of visible ground features, such as when approaching to land over water, darkened areas or terrain made featureless by snow, can create the illusion that the aircraft is at a higher altitude than is the case, leading to a low approach being flown.

When landing at night at an aerodrome with no surrounding

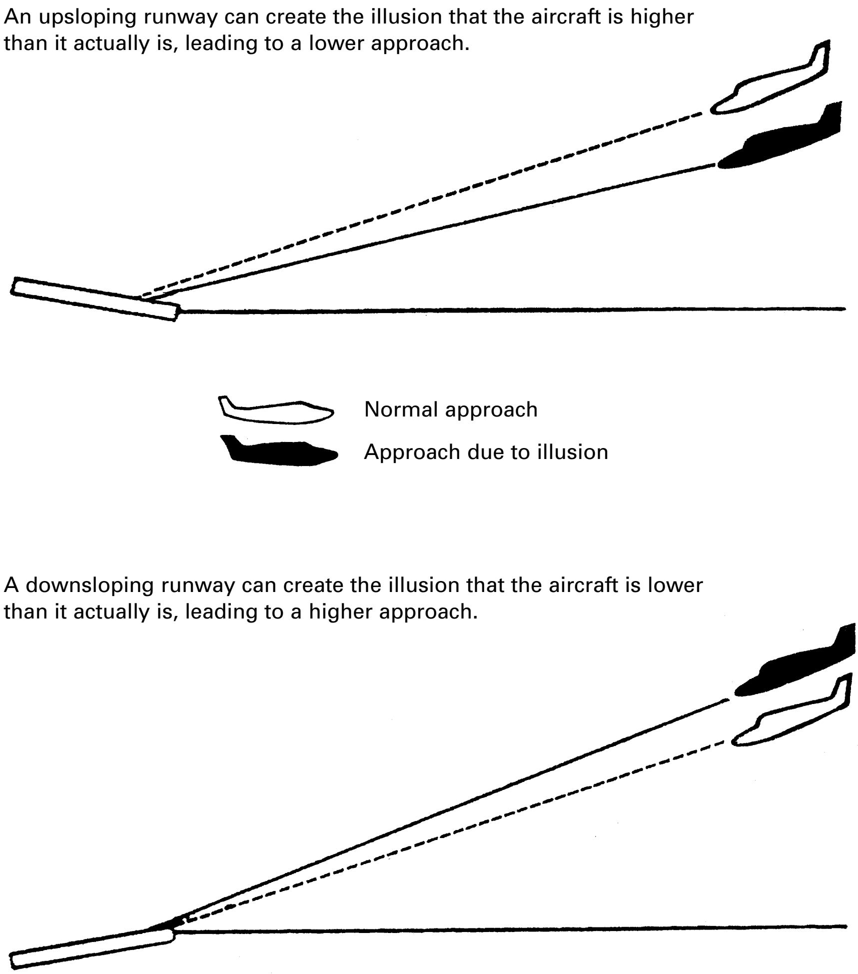

Fig. 3.7 Illusion created during approach caused by sloping runway.

lights, pilots face what has become known as the 'black hole'. This may lead to an excessively low approach being flown with the risk of undershooting the runway. The brain 'constructs' a view of reality utilising visual cues. If the runway edge lights are the only visible cue, there is nothing to provide the dimension of scale leading to false perception of distance and angle.

It is important to realise that visual illusions are the real perception at the time – 'perception is reality'. They occur to pilots of all levels of skill and experience.

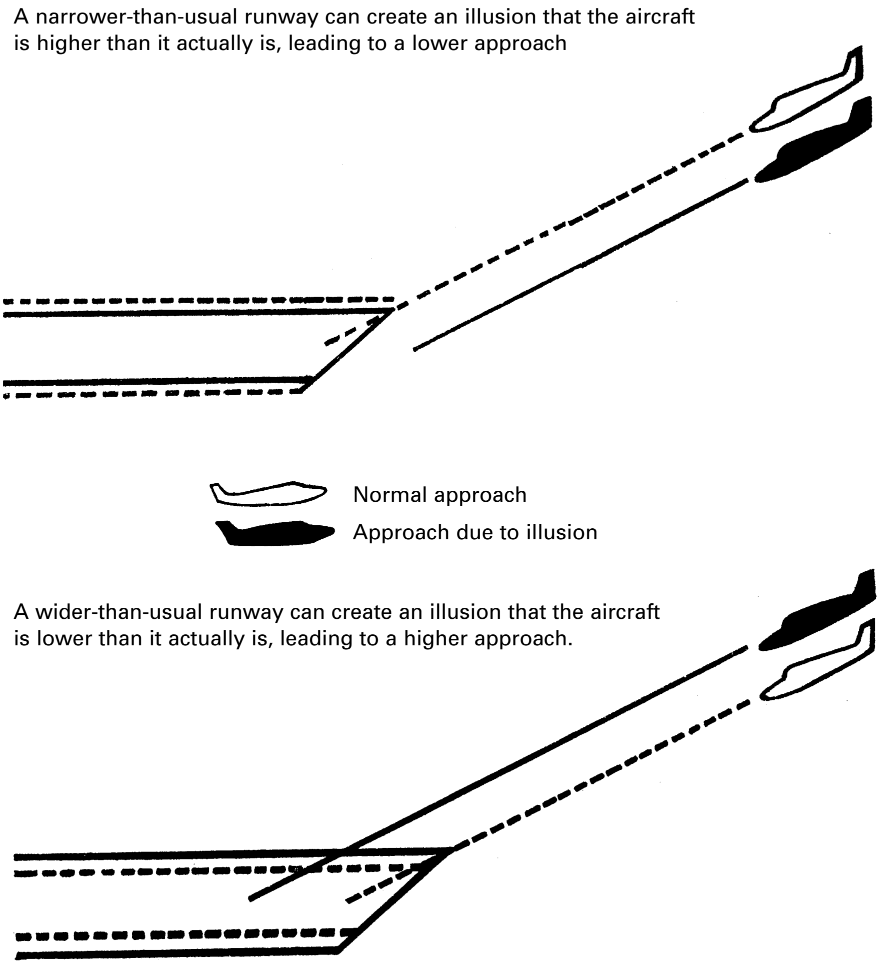

Fig. 3.8 Illusion during approach caused by change in runway width.

Prevention of disorientation

The illusions arising from normal perceptions during flight can be suppressed by believing the aircraft instruments rather than physical sensations. Because instrument flying is an acquired skill, experience and continuing practice in instrument flying is necessary. Precautions to take:

- Never continue flying into deteriorating weather conditions unless suitably qualified in instrument flying.

- In poor visibility, do not attempt to mix instrument flying with visual flying; constant switching between the two sources of reference may in itself lead to disorientation.
- Never continue flying into dusk or darkness unless competent in the use of flight instruments.
- Avoid sudden head movements in flight, particularly when manoeuvring.
- Ensure that when outside visual references are used they are reliable fixed points on the earth's surface.
- Do not fly with a cold or when suffering from any other illness.
- Do not drink alcohol within 12 hours of take-off as its after-effects make the semi-circular canals more sensitive.
- Do not fly when tired or 'one degree under'.
- Maintain practice and proficiency in instrument flying.

If the pilot becomes disoriented when flying in visual meteorological conditions (VMC), a stabilising visual cue can be obtained by looking at the horizon. Disorientation during instrument flight (IMC) can result from conflict between physical sensations and the indications given by the instruments. In such a case, the instruments should be believed.

Chapter 4
Health and Hygiene

4.1 Personal hygiene

In the confines of a cockpit, personal appearance and habits, as well as body and breath odours, can have a significant impact upon other occupants. As well as maintaining one's own health and well-being, personal cleanliness is essential if you wish to share your cockpit with other people.

The respect and confidence of others has to be earned and this can be helped by presenting a professional appearance. Appearing neat, clean and appropriately dressed is important as are personal habits and mannerisms when seeking the respect afforded a pilot in command. It is important to develop and maintain a calm, thoughtful, attentive and disciplined image.

4.2 Common minor ailments

Fitness to fly an aeroplane consists of more than simple absence of physical illness. Overall well-being is a complex interaction between physical, psychological and emotional fitness. Unfitness in one of these general areas can affect the other two leading to a reduction in capacity to perform a task. In particular those tasks which have become automatic through learning and practice can move from the subconscious to the conscious level of action which further reduces capacity for coping with the unexpected or complex tasks. It is important to consider this aspect as well as the effect of the aviation environment on particular ailments. It should also be remembered that a decrease in well-being may make the individual more vulnerable to the effects of conditions such as hypoxia and acceleration.

Colds

A cold is a condition affecting mainly the upper respiratory tract as a result of viral infection (coryza). It may lead to congestion of the mucous membranes within the sinuses, the nose, the throat and the ears. Apart from the overall effect on well-being, aircrew should not fly when suffering from head colds due to the risk of damage to the eardrums or to the sinuses due to pressure changes (barotrauma).

When suffering from a head cold, the mucous membranes within the Eustachian tube and at the back of the nose and throat swell, reducing the rate at which air pressure is equalised; this is particularly noticeable during descent. When the Eustachian tube is completely blocked by mucus and swollen tissue, there may be considerable pain during descent and the increasing pressure within the middle ear can lead to rupture of the eardrum.

An additional risk from flying with a cold is the development of acute vertigo. This can occur during descent when one blocked ear clears suddenly before the other, inducing motion of the fluid in the semi-circular canals of one ear. This is highly disorienting and can lead to sudden incapacitation.

When flying with a head cold, there may also be an effect on the sinus cavities. The sinuses lie within the bones of the face and skull and are connected to the nose by narrow ducts lined with mucous membrane. Congestion due to a head cold (or conditions such as hay fever) can cause a partial or complete blockage of these ducts, which may result in considerable pain during descent to lower altitude.

If suffering discomfort or pain in the sinuses or the ear during descent, the rate of descent should be reduced or temporarily stopped to allow time for the air pressure in the middle ear to equalise with the external ambient pressure. Equalisation can be helped by chewing, yawning and swallowing which causes the small muscles around the nasal end of the Eustachian tube to contract so enabling the mouth of the tube to open. Other assistance to pressure equalisation can be gained using the Valsalva manoeuvre when the nose is pinched by the fingers to close the nostrils, and pressure is increased within the mouth and nose by exhaling against a closed mouth.

It is a common misconception that limiting the aircraft altitude will enable the pilot with a head cold to fly without discomfort or damage to the eardrums. The rate of change in atmospheric

pressure reduces with increase in altitude, so the greatest rate of pressure change occurs near the surface. To limit the flight to, say, an altitude of 1,000 ft in fact exposes the aircraft occupants to the atmospheric layer in which the pressure changes most rapidly during ascent or descent.

Influenza

Influenza is a highly infectious viral illness which can be seriously debilitating. As well as symptoms similar to those of a cold, the condition is accompanied by high temperature, headache, lassitude and debility. An individual suffering from influenza is most certainly unfit to fly as a member of crew and should not travel within the confines of an aircraft because of the risk of infecting other occupants.

After the acute phase of the illness, an individual will continue to feel debilitated and fatigued and may well remain unfit to fly for some weeks after apparent recovery.

Gastro-intestinal upset

This is the commonest cause of acute incapacitation of crew during flight. The cause may be viral or bacterial infection from food or water, or may be the result of irritation due to substances such as alcohol, spices or curried food.

Gastritis is an inflammation or irritation of the stomach lining and may be acute or chronic. Acute gastritis is often triggered by something recently ingested, whereas chronic gastritis can persist for a long period and may not be related to a particular diet. Symptoms include nausea or vomiting as well as sudden incapacitating pain or discomfort.

Gastro-enteritis involves inflammation of the intestine as well as the stomach. It can be very disabling and may result in vomiting, diarrhoea, cramping pains and a raised temperature. Severe abdominal pain caused by stretching of the intestinal wall can lead to fainting or collapse.

It is important to avoid eating reheated or partially cooked food and to avoid drinking water which may be contaminated. It is also

important to remember that gastro-intestinal symptoms may result from eating unfamiliar food and does not necessarily imply that one has acquired a bacterial or viral infection.

Gastro-enteritis is always incompatible with flying.

4.3 Problem areas for pilot health

Hearing loss

The functional anatomy of the ear and the manner in which sound is perceived has already been described in Chapter 3, section 3.3.

There are two major types of deafness or hearing loss. The first is sensori-neural (caused by interference with the ability of the inner ear to process sound) and the second is conductive (the result of sound waves being prevented from reaching the inner ear).

Sensori-neural deafness

Most hearing loss of this sort is due to damage to the delicate sensory hairs or nerve fibres in the cochlea.

Gradual hearing loss begins in childhood as a natural process and is due to cumulative damage and the natural process of ageing (presbycusis). Up to 30% of the hair cells can be lost without measurable hearing impairment. Other causes of sensori-neural loss include:

- bacterial or viral toxins can damage the nerve (examples include mumps, measles, herpes, diphtheria, scarlet fever and syphilis)
- viral labyrinthitis – an infection in the inner ear
- medications which can damage the delicate inner ear structures as a side effect (examples include aspirin, certain antibiotics, quinine and some diuretics)
- Ménière's Disease – this causes dizziness and tinnitus (ringing in the ears) in addition to the deafness
- excessive noise – the sensitive membrane in the cochlea can be damaged by excessive stimulation from loud noise. This is noise-induced hearing loss (NIHL) and although this may be temporary at first, excessive and continuing exposure will lead to permanent damage and hearing loss.
- ageing – causes arteriosclerosis and reduced blood supply.

Sensori-neural deafness is characterised by mild to moderate difficulty in discrimination of speech. The ability to discriminate sounds increases markedly with intensity; even small increases in sound intensity can improve the hearing.

Conductive deafness

This results from interference in the transmission of sound waves from the outer to the inner ear. Causes include:

- impacted ear wax in the ear canal
- middle and outer ear infections; these are characterised by discharge and sometimes pain and almost always require medical treatment
- otosclerosis: in this condition, the bones in the middle ear become fixed and lose the ability to articulate with each other. This is a progressive disorder, beginning in young adults, and can sometimes be corrected by surgery
- perforated eardrum. Most perforations heal naturally; however, chronic perforations may require surgical intervention
- injury to the skull, such as fracture of the temporal bone or concussion.

Prevention of hearing loss

It is important, particularly in the aviation environment, to protect your ears from excessive noise. Wear ear defenders on the airport ramp and use good quality and well-fitting noise attenuating headsets within the aircraft.

Away from the flying environment, avoid loud music and particularly avoid setting high volumes when using personal stereo music devices.

Hearing aids

If damage to the ear structure has resulted in permanent hearing loss, wearing a hearing aid will make the most of the remaining sense of sound. There are many types of aid, depending on which frequencies are no longer perceived. The type of aid to be worn depends on the individual circumstances.

Hearing loss and the use of a hearing aid does not necessarily prevent an individual from holding a flying licence. Each case is considered on its merits, taking account of the ability of the indi-

vidual to perform all the tasks necessary to safely and efficiently operate an aircraft in the flying environment whilst using the hearing aid.

Defective vision

When processing information, the most important sensory input comes from the eyes.

Light reaching the eye is refracted to reach the retina. About 70% of the refraction is produced by the cornea, which is fixed, and the remaining 30% by the lens, which has a variable focal length. Deficiencies in either the cornea or the lens can cause difficulty in obtaining a clear image on the retina. In addition, the shape of the eyeball can also affect visual acuity by determining exactly where the retinal image falls in relation to the focusing apparatus. The functional anatomy of the eye, including the structure of the retina, has already been described in Chapter 3, section 3.2.

Visual acuity may be degraded by the following factors:

- shape of the eyeball
- age
- fatigue
- alcohol
- hypoxia
- smoking.

Long sightedness (hypermetropia)

In this condition the eye is shorter than normal which results in the image being formed behind the retina. Unless the combined refractive power of the lens and cornea can accommodate to focus the image in the correct plane on the retina, blurring of vision will result when looking at a close object. This error can be overcome by the use of a convex lens.

Short sightedness (myopia)

In this condition, the eye is longer than normal. This results in the image being formed in front of the retina and accommodation by the lens is unable to overcome this. This leads to distant objects being

out of focus although close up vision may be satisfactory. Correction can be obtained by the use of a concave lens.

Presbyopia

The ability of the lens of the eye to alter its focal length is known as accommodation. This depends on the elasticity of the lens and this is gradually lost with increasing age. In most people, between the age of 45 and 50 years the lens becomes unable to fully accommodate and this leads to a form of long sightedness known as presbyopia. It starts with difficulty in reading small print in poor light, especially when tired. In aviation it is often first noted when difficulties are encountered reading IFR let-down plates at night. A simple correction using a weak convex lens is normally all that is required.

Cataract

A cataract is an opacity or clouding which develops in the lens of the eye, which can eventually lead to blindness. It can be a phenomenon of ageing and may affect either or both eyes. The affected lens can be replaced surgically and normal visual acuity restored.

Glaucoma

Glaucoma is a condition which causes a rise in pressure in the aqueous humour in the anterior chamber of the eye. It can usually be treated satisfactorily with medication.

Astigmatism

Astigmatism is when light refraction is unequal in the different meridians of the eyeball. This leads to visual distortion and can be corrected by use of a cylindrical lens which has no refractive power along the vertical axis but is concave along the opposite axis.

Corrective spectacles

Flight crew who need correction for long or short sightedness will usually be permitted to fly, as long as their corrected vision allows them to read normal small print in good lighting at a distance of 30 cm and to read 6/9 in each eye on the standard Snellen eye test chart. Myopia is corrected using a concave lens, whereas hypermetropia requires a convex lens.

Those pilots requiring correction for presbyopia may find that

adequate correction is obtained with half glasses, enabling intermediate and distant vision to be utilised by looking over the glasses.

Pilots who need correction for both near and distant vision, e.g. those who were myopic when young and who have become presbyopic, will normally be able to wear suitable correction with bifocal lenses.

The use of earlier generation variable focus lenses (with a continuous increase in power from the upper to the lower part of the lens) was generally not advised when flying an aircraft. The peripheral distortion which could occur with this type of lens may interfere with peripheral vision and could enhance certain visual illusions. These distortions are much reduced in the later generation of lenses, and individuals may find this type of correction to be satisfactory for flying.

When flying at high level, there is less atmospheric attenuation of light levels and a preponderance of light at the blue end of the spectrum. Cumulative high energy blue light can damage the retina, and prolonged exposure to UV light can damage the lens of the eye. However, the cockpit windows (transparencies) filter out most UV light, and further protection is provided by wearing suitable antiglare spectacles.

Glare can be minimised by the use of spectacles which have a neutral grey tint. However, the use of light sensitive lenses ('Photochromic') is not advised because of the time taken for the lens to clear when moving from a bright situation (e.g. above the clouds) to a low light environment (e.g. when coming out of cloud on final approach). The delay in lens clearing may significantly reduce visual acuity at a critical time of flight. It is recommended that separate spectacles are carried, tinted and non-tinted, made up to the individual's prescription.

Spectacles worn when flying should be impact resistant and, ideally, the lenses should be made from polycarbonate or CR39 for strength. Frames should be of thin metal, for minimal obscuration, and should fit comfortably with the telecommunication headset.

Many people find the use of contact lenses to be very convenient. Before using them in the aviation environment, expert guidance should be obtained. If a pilot is cleared to fly when using contact lenses, he or she must be in possession of a pair of spectacles when exercising the privileges of the licence.

The use of a contact lens in one eye for distant visual acuity and a lens in the other eye for near visual acuity is not acceptable. This is because the procedure causes the pilot to alternate his or her vision; that is, a person uses one eye at a time suppressing the other, and consequently impairs binocular vision and close depth vision. Since this is not a permanent condition for either eye in such a case, adaptation does not occur as it does in the case of permanent monocularity. Monovision lenses, therefore, are not acceptable for pilots flying an aircraft.

Hypotension

Hypotension is the term for low blood pressure. Blood pressure is the force exerted against the walls of the arteries by the blood which leaves the heart. It varies during the course of a day, being lowest when the individual is at rest and highest during exercise or times of stress.

Blood pressure is expressed as a ratio of the maximum pressure (in millimetres of mercury) exerted when the heart pumps blood into the circulation (systolic pressure) and the pressure in the arterial system at the moment the heart relaxes between beats (diastolic pressure). Normal blood pressure for an adult is in the region of 120/80 mmHg (systolic/diastolic), although this tends to increase with age.

Sustained low blood pressure is not normally a cause for concern unless it causes symptoms such as frequent fainting or blurred vision.

Causes of hypotension

Blood pressure increases slightly when rising from a lying or sitting position to standing up. In postural hypotension this normal increase does not occur and a sudden change in posture may actually lead to a momentary fall in blood pressure causing faintness.

Orthostatic hypotension may be caused by some medications, particularly those used to treat high blood pressure. It can also be an effect of diabetes or a disorder of the adrenal glands.

Low blood pressure may also result from clinical shock which can be brought about by severe burns, major injuries, severe infections or allergies, excessive blood loss, a heart attack or a stroke.

Hypertension

High blood pressure (hypertension) occurs when the pressure becomes higher than the normal for an individual in a particular age group.

The normal blood pressure is around 120/80 mmHg and this tends to increase with age. Recognising that blood pressure normally increases with age, hypertension may be diagnosed when the maximum blood pressure exceeds:

Age under 39	–	145/90 mm Hg
Age 40–49	–	155/95 mm Hg
Age over 50	–	160/100 mm Hg

Untreated hypertension can be a major factor in the development of cerebro-vascular accident (CVA or stroke).

Causes of high blood pressure

In most cases of high blood pressure, the cause is unknown and this is referred to as essential hypertension.

Blood pressure varies throughout the day and is affected by physical and emotional states. Thus a single high reading is not usually considered significant, but repeated high readings will indicate that some action is necessary.

The usual first steps are reduction to ideal weight, possibly salt restriction, a gentle exercise programme, and avoidance of alcohol. The individual will also be strongly advised to give up smoking, as this is an added risk for the development of heart disease.

The next step is control by drugs. Drugs can lower blood pressure by acting in a variety of ways and occasionally people with hypertension may need to take a combination of different drugs. Many drugs used for controlling hypertension have significant side-effects, but there are some which do not and which will allow an individual to continue to hold an aircrew licence. Hypertension usually needs to be controlled throughout life as it rarely improves on its own.

If hypertension is left untreated it will cause damage to the arteries, especially those of the heart, brain and kidneys. This increases the risk of suffering a heart attack, stroke or kidney damage. However these risks are significantly reduced once the hypertension is controlled.

Coronary artery disease

Although blood is constantly flowing through the heart chambers, the heart muscle itself derives oxygen from its own network of blood vessels. These are the coronary arteries, which encircle the heart like a crown. In coronary heart disease, these vessels become narrowed, reducing blood flow to the heart muscle.

When insufficient blood is reaching the heart muscle, ischaemia (oxygen starvation) occurs. Ischaemia may lead to chest pain (angina pectoris), a heart attack (myocardial infarction) where the muscle is damaged and the chest pains caused are prolonged, or occasionally to an erratic heartbeat (arrhythmia) which may be followed by heart failure.

Progressive narrowing of the coronary arteries is usually associated with atherosclerosis which is the build up of fatty deposits (atheroma) on the inner lining of the arteries. Smoking, diabetes, high blood pressure, a family history of heart disease and high levels of certain types of cholesterol appear to be contributing risk factors.

As deposits accumulate, the arteries become narrower. This increases the risk of a heart attack which occurs when a narrow artery becomes blocked, by a clot (coronary thrombosis) or a fragment of fatty deposit, or by sudden spasm of a coronary artery. Atherosclerosis may develop for many years, and in some cases even begins in childhood. Often the first symptom is an abrupt heart attack.

There are no simple tests which will give a picture of the state of the coronary arteries, but the electrocardiogram (ECG) may be of some limited value. The ECG records the electrical activity of the heart muscle. It shows the heart rhythm and the order in which different parts of the heart are contracting. It also gives some indication of the condition of the heart muscle and can sometimes show evidence of damage due to poor blood supply. A stress or exercise ECG is performed when the individual is walking or running on a treadmill and thus putting some stress on the heart. This test will occasionally show changes due to damage which are not seen on a resting ECG. However, its use as a screening tool is limited by the occurrence of false positive results when the recording may indicate damage to the heart which in fact proves not to be the case. An exercise ECG is used when suspicions of heart disease have already

been raised, possibly by symptoms of pain or by changes seen on a resting ECG.

The risk of developing coronary heart disease can be reduced as follows:

- do not smoke
- use diet and exercise to maintain desirable weight
- do not drink excessive amounts of alcohol. Some studies suggest that a daily glass of wine may provide some protection from the development of heart disease, but the criteria regarding the consumption of alcohol before flying, as given in section 4.4, apply.
- eat plenty of fresh fruit and vegetables
- eat oily fish in preference to red meat
- use olive oil for cooking
- take exercise two or three times per week sufficient to put the heart rate into the 'training range' for 20 minutes. The training pulse rate is calculated by subtracting age from 220, which gives maximum heart rate. The training range is 60–80% of this value
- minimise consumption of fat.

Obesity

Obesity is an excess of fatty tissue in the body. Although body weight varies considerably between healthy people, it is generally accepted that the ideal weight for an adult is about the weight of the individual at age 21. With increasing age, the body's metabolic rate tends to reduce and thus less energy is expended. Food taken in has to balance expended energy and if there is an excess of intake this will be stored as body fat. Although exercise is beneficial to general health, it is a very inefficient way of burning off excess calories and the only practical way to control weight is to reduce food intake.

Height and weight are related by the body mass index (BMI), the normal value being 25. The index (Figure 4.1) is derived by dividing the body weight in kilograms by the height in metres squared, i.e. BMI = kg/m^2. The BMI is only a guide and should be treated with caution when determining the ideal weight for an individual. For example, a fit and healthy individual with well-developed muscles may actually have a BMI indicating over-weight or even obesity, when in fact the extra weight is derived from the increase in muscle

	BMI for males	BMI for females
Underweight	up to 20	up to 19
Normal weight	20–25	19–24
Overweight	25–30	24–29
Obese	> 30	> 29

Fig. 4.1 Body mass index.

mass. The individual body shape (morphology) must also be taken into account.

Obesity (when the BMI exceeds 30) is considered to be a risk factor for hypertension, gout, diabetes, osteoarthritis, and possibly coronary heart disease. It also reduces tolerance to hypoxia, decompression sickness and acceleration.

Nutrition

Food is the source of energy for vital activities and the materials necessary for body building and maintenance. The energy is locked up in the food materials available. Often these substances are not in a suitable form for the energy to be immediately available and the food has to be suitably altered.

First, the food must be taken into the body – *ingestion*. Secondly, the food is frequently not soluble or diffusible and must be made so in order that it can be absorbed into and distributed about the body – *digestion and absorption*. The food then has to be broken down into small molecules which can be synthesised into the more complex ones required for the maintenance of particular cells and tissues, as well as the formation of high energy compounds to release free energy – *assimilation*. Finally, not all the food taken in can be digested and absorbed and this has to be eliminated – *egestion*.

Thus the body needs adequate levels of essential nutrients to maintain good health. It needs proteins, fats, carbohydrates, vitamins, minerals and trace elements in the right amounts and proportions. A balanced intake of a wide variety of foods is important.

Vitamins are found in a variety of foods, although processing can reduce the vitamin content. They are either fat-soluble (vitamins A,

D, E and K) or water-soluble (vitamins B and C). Fat-soluble vitamins can accumulate in the body, so it is important to avoid taking excessive amounts by way of supplemental medication. Water-soluble vitamins are removed from food by boiling or soaking.

Although the body requires only small amounts of vitamins, deficiency can cause a variety of symptoms such as malaise, susceptibility to infection and slow wound healing. Serious deficiency is usually seen only in cases of starvation or extreme poverty, or in the presence of other medical conditions, and can lead to conditions such as scurvy (vitamin C deficiency), rickets or osteomalacia (D), beri beri (B1) and pernicious anaemia (B12).

The three principal minerals in the body are calcium, phosphorous and iron. Minerals and trace elements are required to be ingested by the body in very small amounts and include calcium, phosphorous, magnesium, sodium, potassium, chloride, iron, zinc, copper, selenium and iodine. The World Health Organisation publishes the recommended daily dietary intake, and this is usually well exceeded by the normal western diet.

The western diet is high in fat, sugar and salt, and low in fibre. On average, in the western diet fat provides 42% of the daily energy intake. For a healthy diet, many authorities recommend that this should be reduced to about 33%.

The body converts saturated fats into cholesterol. Some cholesterol plays an important part in body metabolism, but excess cholesterol can lead to the formation of fatty deposits in the blood vessels. This in turn can lead to clogging of the small vessels such as the coronary arteries. Polyunsaturated fats do not lead to the production of cholesterol, and they can be part of a balanced diet.

Carbohydrates provide half as many calories as fat, and are the major source of energy for the body. The main carbohydrates are starches and sugar. It is considered preferable to obtain carbohydrates from starch in root vegetables, legumes, cereals and grains, or from the natural sugars found in fruit and some vegetables, rather than from refined sugar.

Breakfast is an important meal and should provide about 25% of the daily calorie intake. Hunger pangs during the day are often ascribed to a state of hypoglycaemia or low blood sugar. In fact, the blood sugar level is maintained by the release of stored sugar from the liver and the condition of true hypoglycaemia does not occur in a

healthy individual. Nonetheless, the sensation of hunger can be alleviated by a snack.

Excess salt in the diet has been linked with high blood pressure. The body requires about 5 grams of salt (sodium chloride) each day, but the average western diet provides around 12 grams per day in processed foods or as added salt.

Fibre, or roughage, is important in providing bulk to assist the excretion of waste products. It binds with cholesterol and assists in its removal from the body, and can delay the absorption of sugar. The average western diet includes around 12 grams of fibre per day and it is recommended that this should increase to around 18 grams.

Fat intake can be reduced by grilling, poaching, baking or casserolling food rather than frying it. Polyunsaturated fats such as sunflower oil, or olive oil, should be used for cooking in preference to saturated animal fats such as butter or lard.

Sugar intake can be reduced by drinking tea and coffee without sugar and eating fruit and nut mixes instead of desserts and sweets.

However, it is important to remember that eating food is an important component of social activity which contributes to overall well-being. Thus common sense is the order of the day, applying moderation and balance to all activities.

Tropical climates and epidemic disease

The earth's tropical zones extend on either side of the equator and have a very different type of climate to that encountered in the temperate regions of Europe. The dry season occurs in winter when the temperatures are very high in the daytime and much lower at night. Relative humidity levels range between 16 and 30%, solar radiation is strong and the atmosphere tends to be highly charged with electricity.

In the summer season, heavy rainfalls occur leading to high relative humidity levels, lower but even temperatures and much cloud cover. It is necessary to provide protection from the sun with the use of sun blocking creams, wide brimmed hats and wearing sunglasses with lenses which filter out ultra-violet light.

Heat exhaustion can be avoided by protecting oneself from the sun and drinking adequate fluid. Loose fitting light clothing will also help.

Many diseases are endemic in tropical climates and it is important for individuals to take particular care.

Diseases may be spread by one or more of the following methods.

- *Direct contact* – where the infection is passed directly from an infected person to another individual by direct physical contact, e.g. leprosy and venereal diseases. Tetanus infection is acquired from spores in soil entering the body via a puncture in the skin.
- *Airborne infection* – where the infection is passed via droplets in the air. Examples include polio or diphtheria, and legionnaire's disease, which may be spread by droplets of contaminated water sprayed in a fine mist from air conditioning systems or shower heads. Tuberculosis (TB) is spread via droplets from person to person.
- *Infection by insects* – where the bite of an infected insect spreads the illness from one person to another, e.g. malaria and dengue fever.
- *Infection by animals* – where the infection is passed by the infected animal by a bite, lick, or scratch or contact with animal waste, e.g. rabies.
- *Infection by food* – commonly called food poisoning, which is caused by eating contaminated or infected food.
- *Infection by water* – includes the transmission of diseases such as typhoid fever, cholera and dysentery.

Malaria is a world-wide disease, which is potentially fatal. It is spread by the bite of the anopheles mosquito. Yellow fever is spread by a different strain of mosquito, which is the same strain which also transmits dengue fever. Mosquitoes can also transmit certain parasitic worms known as filariasis. As well as the mosquito, parasites can also be transmitted by black fly and tsetse fly.

Certain water snails can be responsible for the transmission of a parasitic disease, known as bilharzia, by releasing parasitic larvae into the water.

Bites from wild animals and even domestic pets can transmit rabies, which is a potentially fatal disease.

The first thought when considering precautions to be taken is often the receipt of appropriate vaccinations before travel. In fact,

although it is important to use such prophylaxis, sensible precautions during the time spent in the tropical climate are of equal importance. These include:

- Avoid being bitten by insects such as mosquitoes. They generally fly after dark, so use insect repellent and cover up arms, neck and legs when going out at night.
- Avoid contact with stray animals of all types.
- Avoid swimming in still water and lakes.
- Choose food which is hot and freshly cooked and avoid items such as cold cooked meats, shellfish, cream, pastry cream and ice cream. It is important to remember that water, and therefore ice, in many areas of the world may be contaminated with the organisms which cause diseases such as dysentery and typhoid fever.

Sexually transmitted disease is an ever present threat to the sexually active. Human immunodeficiency virus (HIV) and hepatitis B and C infection are now established as real risks in both the homosexual and heterosexual communities world wide. Remember, alcohol makes the drinker careless. Safe sex means safe sex *every* time.

Hepatitis B is a virus which infects the liver and has an insidious onset. Some individuals will go on to develop hepatic cell carcinoma with a fatal outcome. There are two types of immunisation product available: a vaccine which induces an immune response, and a specific immunoglobulin which provides passive immunity and can give immediate but temporary protection after accidental inoculation with the virus.

Hepatitis C is similar to B. There is currently no vaccine to protect against hepatitis C.

Hepatitis A is usually milder than hepatitis B and is very seldom fatal. It is usually transmitted by the faecal oral route, generally after the ingestion of contaminated food or drink.

Very few tropical diseases are limited strictly by geography. Malaria is occasionally found in the United Kingdom and was widespread in parts of the Thames Estuary at the beginning of the twentieth century. Cholera was widespread in the United Kingdom and parts of Europe in the nineteenth century. This suggests that

these are diseases of poor hygiene and sanitation rather than just diseases of the tropics.

Malaria is still the world's biggest killer and too much reliance should not be placed on the use of anti-malarial tablets. It is important to avoid being bitten by insects. Nonetheless, compliance with effective anti-malarial medication protects against severe malaria and reduces the risk of a fatal outcome.

Yellow fever is also insect borne, but the primary protection against this is vaccination. The vaccine is extremely efficient, very safe and effective for 10 years.

Other vaccinations may be useful but are less effective and should not be relied upon for sole protection.

Vaccinations for typhoid and polio are reasonably effective, and gamma-globulin for hepatitis A is useful for short-lived protection. Hepatitis A vaccine (Havrix) is available for frequent travellers to high risk areas or those who stay for more than three months. Cholera vaccine is not effective for the individual, although it may have some value in preventing epidemic spread.

In summary, epidemic and tropical diseases can be avoided as follows:

- maintain scrupulous personal hygiene
- use appropriate vaccines and preventative medications
- be aware of the risks from diseases spread by contaminated food and water and take appropriate precautions
- avoid contact with insects and stray animals
- maintain constant vigilance and health awareness
- spray aircraft interiors with insecticide when leaving areas of endemic insect-borne disease (disinsection).

4.4 Intoxication

Intoxication is the effect on the body of noxious substances which may be harmful.

Tobacco

Tobacco is a highly addictive drug which is usually taken by smoking. Less common uses include chewing tobacco and sniffing

'snuff'. The use of tobacco is implicated in the development of many diseases including heart disease, circulatory disease, lung disease and numerous cancers.

Combustion of tobacco, such as in a cigarette, produces carbon monoxide and this binds readily with the haemoglobin in the red blood cells to produce carboxy-haemoglobin. This reduces the amount of haemoglobin available to bind with oxygen and effectively leads to mild hypoxia. An individual who smokes 20 cigarettes a day will have a carboxy-haemoglobin level at sea level of approximately 7%, giving an equivalent altitude of 4,000 to 5,000 ft. Regular smokers adapt by producing more haemoglobin and this in turn can lead to thickening of the blood.

Secondary smoking is the effect of smoking on the immediate companions of an individual who is smoking tobacco. Evidence of the long-term effects on the health of individuals subjected to secondary smoking is not clear, but the immediate effects are unpleasant and can cause headache as a result of breathing in the secondary smoke. Smoking may reduce tolerance to hypoxia and acceleration, and reduces night vision.

Regular tobacco smoking is a major risk factor in the development of cardiovascular disease and cancer, and the avoidance of tobacco intoxication can contribute significantly to an individual's long-term health and well-being.

Alcohol

Alcohol, drunk socially in the form of wine, beer or spirits, is a form of ethyl alcohol which acts as a depressant on the central nervous system. It has an effect similar in many ways to an anaesthetic.

When alcohol is consumed it is absorbed from the stomach into the bloodstream. It is carried to the brain where it initially affects the area which controls thinking, worrying and the alarm system. Initially the individual becomes more relaxed and less prone to worry, leading to a decrease in alertness.

The alcohol then affects the area of the brain which controls speech and muscular activity, resulting in impairment of speech and muscular co-ordination. Continuing absorption of alcohol eventually affects all areas of the brain which can lead to coma.

It has been shown that a blood alcohol level of 30 mg/100 ml of blood increases the likelihood of an individual having any form of

accident. Positive impairment of judgement can be measured at 50 mg/100 ml and by 150 mg/100 ml, loss of self-control will occur. Double vision and memory loss will occur at 200 mg/100 ml, while most people will begin to lose consciousness at around 400 mg/ 100 ml.

Alcohol is removed from the blood and broken down by the liver at a rate of approximately 15 mg/100 ml/hour. The consumption of $1\frac{1}{2}$ pints of beer or three small glasses of whisky will result in a blood alcohol of about 45–50 mg/100 ml in most people, and so it will take up to four hours for this amount of alcohol to be removed from the blood.

It is important to note that performance can be affected by the products of alcohol metabolism, in addition to the acute toxic effects. Despite popular belief, an individual cannot speed up the rate at which alcohol leaves the body. The use of black coffee, steam baths or fresh air will not change the rate of oxidation, and sleeping off the effects of alcohol may actually slow the rate of oxidation because all body functions slow down during sleep. Although drinking while taking food reduces the rate at which alcohol may be absorbed into the bloodstream, it does not affect the rate at which the alcohol is metabolised and removed from the bloodstream.

It has been suggested that the effect of a given amount of alcohol will increase with altitude because alcohol interferes with the brain's ability to use oxygen. Alcohol is absorbed rapidly into the bloodstream, and the brain, being a highly vascular organ, is sensitive to all changes in the composition of the blood. Thus the reduced oxygen concentration at altitude coupled with the effects of alcohol will impair clear thinking and decision making. However, the scientific evidence for this phenomenon is conflicting.

Because individuals vary in the way they absorb alcohol, it is difficult to give hard and fast rules on the quantity of drink consumed in relation to time allowed before flying. Research has confirmed that even in light aircraft, blood alcohol concentrations of 40 mg/100 ml (half the current UK legal driving limit) are associated with significant increases in errors committed both by inexperienced and experienced pilots. Even a single alcoholic drink can produced a measurable loss of performance, although an individual may not consider himself to be affected.

It is also important to remember the after effects of alcohol on the

semi-circular canals which leads to an increase in susceptibility to disorientation and motion sickness.

It has long been accepted that at least eight hours should elapse between drinking small amounts of alcohol and flying (8 hours 'bottle to throttle'). In fact, a safer minimum is 12 hours and where larger amounts have been consumed, the period before flying should be proportionally greater.

Alcoholism

The World Health Organisation (WHO) originally defined an alcoholic as an excessive drinker whose dependence on alcohol has reached such a degree that there is a noticeable mental disturbance or an interference with mental and bodily health. The definition also includes a disturbance with inter-personal relations and smooth social and economic functioning, or showing the early signs of such development. However, the inexactness of the term led the WHO in 1979 to disfavour it, preferring the narrower formulation of 'alcohol dependence syndrome' as one among a wide range of alcohol related problems. However, despite its ambiguous meaning, 'alcoholism' is still widely used as a diagnostic and descriptive term, and can be defined as 'when the excessive use of alcohol repeatedly damages a person's physical, mental and social life'.

Symptoms and signs of alcohol dependence syndrome include:

- subjective awareness of compulsion to drink
- narrowing of the drinking repertoire
- dominance of drinking over other activities
- altered tolerance to alcohol
- repeated withdrawal symptoms
- relief or avoidance of withdrawal symptoms by further drinking
- reinstatement of drinking after abstinence
- interference with ability to socialise and work
- marital problems
- conflict with the law.

Alcohol dependence syndrome may result in cirrhosis of the liver, peripheral neuropathy, cardiomyopathy and pancreatitis.

Alcohol is usually measured in units and one unit of alcohol is equivalent to one standard drink.

A standard drink is a volume of beverage alcohol that contains

approximately the same amount (in grams) of ethanol, regardless of the type of beverage. In the UK, a unit of alcoholic beverage contains approximately 8–9 g of ethanol. For example, a half pint of normal strength beer equates to one unit of alcohol whereas a half pint of strong ale or lager equates to two units of alcohol. A standard glass of table wine equates to one unit and thus a normal bottle of table wine contains seven units of alcohol.

The recommended maximum intake for a man is 21 units per week or 5 units in a day, whereas for a woman the recommended maximum is 14 units per week or 3 units in a day.

It is illegal for a crew member to operate when under the influence of alcohol because of the effects on judgement and psychomotor performance. Alcohol dependence syndrome can be considered as a pathological medical condition and is thus amenable to treatment. When a colleague is suspected of being alcoholic he or she should be offered full support and encouraged to seek professional help.

Drugs and self-medication

A drug may be a psychoactive substance such as a narcotic, or it may be a pharmaceutical or medical compound used for therapeutic purposes. Drugs prescribed for a particular medical condition are used in controlled circumstances although it is important for the prescribing doctor to be aware of how any side-effects may be important in aviation. Common side-effects may include drowsiness, depression of sensory function, decreased co-ordination, and impaired judgement. Although side-effects may be minor in the ground environment, the effects may be less predictable at altitude. However, a pilot undergoing treatment for an ailment is likely to be unfit to fly, quite apart from the side-effects of any medication.

A pilot taking any form of medication should ask him or herself the following questions.

- Do I feel fit to fly?
- Do I really need to take any medication at all?
- Have I given this particular medication a personal trial on the ground for at least 24 hours before flight, to ensure that it does not have any adverse effects whatsoever on my ability to fly?

- If it is a prescribed drug, does my physician know that I am a pilot?

If the answer to any of these questions is 'No', then the pilot should not fly.

Anti-histamines

Anti-histamine drugs are commonly used in cold cures and for the treatment of hay fever, asthma and allergies. Many easily obtainable nose sprays and drops contain anti-histamines which can lead to drowsiness and can affect the sense of balance and co-ordination. It is advisable to allow at least 24 hours before flying after completing treatment involving anti-histamines.

Sedatives and analgesics

These drugs act on the central nervous system and may well suppress mental alertness. As always, the underlying medical condition probably means that an individual is unfit to fly as a member of crew.

Amphetamines and stimulants

So-called pep pills and weight reducing agents often contain amphetamines. Stimulants such as caffeine, Dexadrine and Benzedrine may be used to maintain alertness but they can become habit forming. They act as a stimulant to the central nervous system, leading to insomnia, restlessness, irritability and excitability, nervousness, euphoria and sometimes dizziness, although the effect varies from one individual to another. However, in all cases their use can cause over-confidence and adversely affect judgement.

If coffee is not sufficient as a stimulant, you are not fit to fly. However, remember that excessive coffee drinking itself may be harmful, leading to irritation of the heart muscle which can cause palpitations and changes to the ECG, as well as affecting performance.

Caffeine is a component of coffee, tea, cocoa, and chocolate beverages, as well as soft drinks such as cola. The amount ingested depends upon the strength and volume of the drink, but the following are typical values for an average cup:

Coffee	–	65–115 mg
Tea	–	approx 60 mg
Cola	–	30–60 mg

An average coffee intake is three to four cups per day, which gives 360 to 440 mg caffeine. The fatal dose to humans is 10 g (100 cups of coffee), but an intake in excess of 20 cups of coffee per day is likely to cause symptoms and reduce an individual's performance. In fact pilot performance has been shown to be affected by as little as 250 mg of caffeine (2 to 3 cups of strong coffee).

Antibiotics

Antibiotics such as penicillins and tetracyclines may have short-term or delayed side-effects, which vary between individuals. Their use usually indicates an underlying infection which means that the pilot is not fit to fly. However, occasionally low doses of antibiotics are used long-term for chronic conditions such as skin ailments. In these cases it is important to take the drug for a period on the ground to ensure the absence of side-effects before considering flying as a crew member.

Anti-hypertensives

Many drugs and combinations of drugs are used to control high blood pressure. In all cases, an authorised medical examiner or specialist in aviation medicine must be consulted to determine fitness to fly.

Anaesthetics

Following the use of local or general anaesthetic, including dental anaesthesia, at least 24 hours should elapse before returning to flying. In some cases, a longer period may be necessary and account needs to be taken of the underlying condition requiring the use of the anaesthetic drug.

Other medications

Many preparations marketed contain a combination of medicines. It is essential that if there is any change in medication or dosage, however minor, there should be no attempt to fly until the absence of side-effects has been confirmed.

If you are ill and need treatment, it is important to ensure that the treating doctor knows that you are a pilot or flight crew member and should also be told if you have recently been abroad.

Psychoactive substances

All psychoactive drugs are addictive and there is a wide range available. Drugs commonly used for recreation include cannabis, ecstasy, cocaine, heroin and various hypnotics and tranquillisers. All these drugs affect the central nervous system and impair cerebral function.

Pilot performance can be impaired for as long as 24 hours after smoking a moderate social dose of marijuana and the user may be unaware of the drug's effects. Marijuana impairs those mental activities requiring conscious thought, such as retention of information and reasoning, particularly when difficult tasks are attempted.

Use of any of these drugs is incompatible with fitness to fly.

Toxic hazards

Any article or substances capable of posing significant risks to the health and safety of an aircraft or its occupants are classified as 'dangerous goods'. As well as articles carried in flight, the materials used in the manufacture of furnishings and trim materials can be extremely toxic when released by fire. Some fire extinguishers may also produce toxic fumes when used in confined spaces.

Dangerous goods may include:

- explosives of any nature
- flammable liquids and solids including items such as paint removers, paints and varnishes, petrol, thinners, alcohol, matches and fire-lighters
- oxidising materials, such as nitrates
- corrosive liquids, such as battery acids, mercury, and certain cleaning compounds
- compressed gases including most household sprays
- oxygen cylinders not certified for use in aviation.

Mercury can be particularly hazardous in an aircraft. It causes rapid

corrosion of the aircraft metal structure, giving off highly toxic fumes. Mercury can be present in certain batteries and medical instruments and strict precautions to prevent risk of spillage or leakage must be taken if these are carried on board.

Carbon monoxide

Carbon monoxide is produced by incomplete combustion of carbonaceous material and is also present in the exhaust fumes of piston engines and tobacco smoke. Although carbon monoxide itself is colourless, odourless and tasteless, it is often associated with gases and fumes which can be detected by smell or sight.

Carbon monoxide is highly poisonous because of the ease with which it combines with haemoglobin in the red blood cells, displacing oxygen to form carboxy-haemoglobin. Haemoglobin has an affinity for carbon monoxide 200 times greater than its affinity for oxygen. A proportion of carbon monoxide in the air greater than 1 part in 200 leads effectively to the development of hypoxia and its associated effects.

A short exposure to high concentrations of carbon monoxide will have a serious effect but it must be appreciated that similar effects will result if exposed to lower concentrations for longer periods. Concentrations of carbon monoxide exceeding 1 part in 20,000 parts of air can be hazardous.

The symptoms are progressive starting with headache, nausea, dizziness and a reduction in vision. Continuing inhalation of carbon monoxide eventually leads to vomiting, loss of muscular power, unconsciousness and death. Because of the great affinity of haemoglobin for carbon monoxide, the effects are cumulative. This means that a pilot who flies several times in an aircraft leaking exhaust fumes into the cabin will develop carbon monoxide poisoning.

Unlike the symptoms of hypoxia due to lack of oxygen which can be rapidly remedied by breathing oxygen or descending to a lower altitude, recovery from carbon monoxide poisoning may take days or weeks because of the affinity between haemoglobin and the carbon monoxide gas molecules.

Susceptibility to carbon monoxide poisoning increases with altitude because of the reduction in oxygen partial pressure. Tobacco smoking also increases susceptibility.

The principal signs of carbon monoxide poisoning are cherry-red lips and flushed cheeks, with symptoms being headache and a reduced state of vigilance.

Actions in the event of toxic contamination

The drill to be followed depends on individual aircraft types and on the underlying cause of the toxic symptoms. However, in general the following actions should be taken:

- shut off the cabin air heater
- open all sources of fresh air to the cabin (including windows or DV panels if applicable)
- avoid cigarette smoking
- if oxygen is available it should be used by all occupants of the aircraft cabin
- if any symptoms develop, the aircraft should be landed as soon as possible and subjected to a full engineering inspection before flying again.

4.5 Incapacitation during flight

Commercial pilots who operate in a multi-crew environment regularly practise the drills to be followed in the event of incapacitation of one flight crew member. However, most general aviation involves single pilot operation which means that in-flight incapacitation may have more serious consequences.

Symptoms and causes

In-flight incapacitation may be partial or total. Partial incapacitation may not be immediately obvious. Any form of pain or discomfort may affect mental performance with a resulting effect on a pilot's ability to exercise judgement and make sensible decisions. Common causes of incapacitation include the following.

- gastro-intestinal disorders
- fatigue, disruption of circadian rhythms
- anxiety and stress
- sinus or ear pain due to barotrauma, particularly during descent

- hypoxia
- carbon monoxide intoxication
- acute medical conditions such as kidney stones
- cardiovascular problems such as angina or heart attack
- the side effects of medication
- decompression sickness.

Incapacitation may occur as a result of a fit or a faint. A faint results from insufficient blood reaching the brain, which can be caused by a sudden change in posture or from shock. On the other hand, a fit is caused by sudden activity of the nervous system leading to signs such as muscle twitching or spasm. It can be caused by conditions such as epilepsy, raised pressure in the brain, infection of the brain or an abnormally high temperature. Latent epilepsy may be detected from an electroencephalogram (EEG) which is a recording of brain wave activity.

One type of epileptiform fit can be induced in a susceptible individual by the flicker of helicopter rotor blades or a propellor in the sunlight. This produces a stroboscopic effect at flash frequencies between 5 and 20 Hz, known as the flicker effect, and is most likely to occur on the ground prior to take-off. Even if the individual is not susceptible to epilepsy, it can be an unpleasant sensation. It can be minimised by the affected individual closing eyes, wearing anti-glare spectacles, moving to a seat in the shade, or by the aircraft being turned out of the sun.

The most dangerous form of pilot incapacitation is the progressively insidious type, rather than sudden collapse. Neither the crew member him/herself nor other members of the crew may realise that the individual's well-being and performance is gradually deteriorating, until a critical stage is reached when the affected individual collapses or it is realised that he/she is no longer in the operating loop.

Examples of conditions leading to insidious incapacitation include the development of infections with the onset of high temperature and malaise, gastro-enteritis, certain cardiovascular conditions such as irregular heart beat (arrhythmia) or coronary thrombosis, and certain neurological conditions such as petit mal or narcolepsy (the inability to keep awake even when in sleep credit).

All crew members must remain vigilant, and on passenger-carrying aircraft this vigilance extends to members of the cabin

crew who can monitor the well-being of the flight deck technical crew.

Fitness to fly and to operate an aircraft is a personal responsibility. However, it is recognised that many medical conditions can strike without warning, and the risk to flight safety from incapacitation is reduced by multi-crew operation.

Operational coping procedures

The overwhelming importance is the safety of the aircraft and its occupants. It may be necessary to declare an emergency to ensure a priority landing at the nearest suitable airfield.

Symptoms should be treated appropriately, e.g. a 'stair step' descent should be flown in the event of sinus or ear pain and oxygen (if available) should be used in the event of any breathing problem or chest pain. In the event of incapacitation of a front seat occupant, it is important to ensure that the upper torso restraint is tightened sufficiently to prevent the individual collapsing on to the flying controls. Regular training of incapacitation drills in a flight simulator will reduce the flight safety risks of incapacitation occurring to a crew member during flight.

Flying after SCUBA diving

The development of decompression sickness may be related to recent SCUBA diving. Sufficient time should be allowed for the body to get rid of the excess nitrogen absorbed during the diving. Decompression sickness from dissolved nitrogen coming out of solution can occur even at low altitudes leading to serious incapacitation. This is true whether flying in a non-pressurised or pressurised aircraft.

It is important to avoid flying for at least 12 hours following diving which has not required controlled ascent (non-decompression diving), and at least 24 hours after diving which has required controlled ascent (decompression diving). For flying at cabin altitudes above 8,000 ft, at least 24 hours should elapse following any form of SCUBA diving.

It is the pilot's own responsibility to ensure his or her fitness to discharge the duty of care to passengers, other users of the air and

people on the ground. Before flying, one should consider whether one is physically and mentally fit to fly. A helpful check list mnemonic is I'M SAFE –

Illness
Medication
Stress
Alcohol
Fatigue
Emotion.

Part 3
Basic Aviation Psychology

Chapter 5
Human Information Processing

The human interacts with both the machine and the environment. Human information processing involves transmission of signals from the sensory system via neural pathways to the brain. The information is interpreted within the brain leading to appropriate decision making and motor actions. For this process to work efficiently, the sensory signals should not conflict and the brain must store information in the form of memory to facilitate interpretation of the received signals. However, there are potential weak links in the process leading to actions which are inappropriate to a given situation. Sensory information can be misleading, e.g. illusions can arise from the visual system or from the vestibular system in the inner ear. Thus it is important to gain knowledge which is acquired through study and past experience, to be used as part of the human information process.

Figure 5.1 shows a simple representation of a model of human information processing.

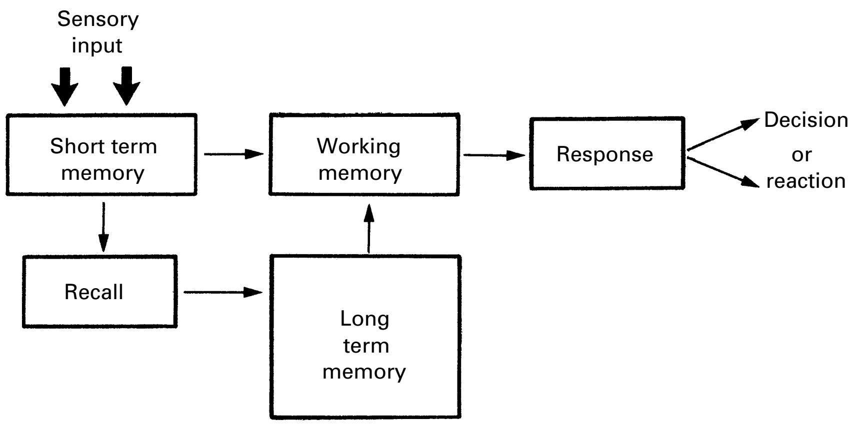

Fig. 5.1 Model of human information processing.

An alternative model, showing a feedback loop, is given in Figure 5.2.

If a stimulus is expected, an appropriate response will be prepared. However, if the stimulus received is not the expected one, the response already prepared is still likely to be carried out. The normal response time for a simple task is 0.2 sec.

Motor programmes, or mental schemata, are behavioural subroutines not requiring conscious thought. American psychologist John R. Anderson named the three phases during their development as:

cognitive	–	declarative knowledge
associative	–	knowledge compilation
automatic	–	procedural knowledge

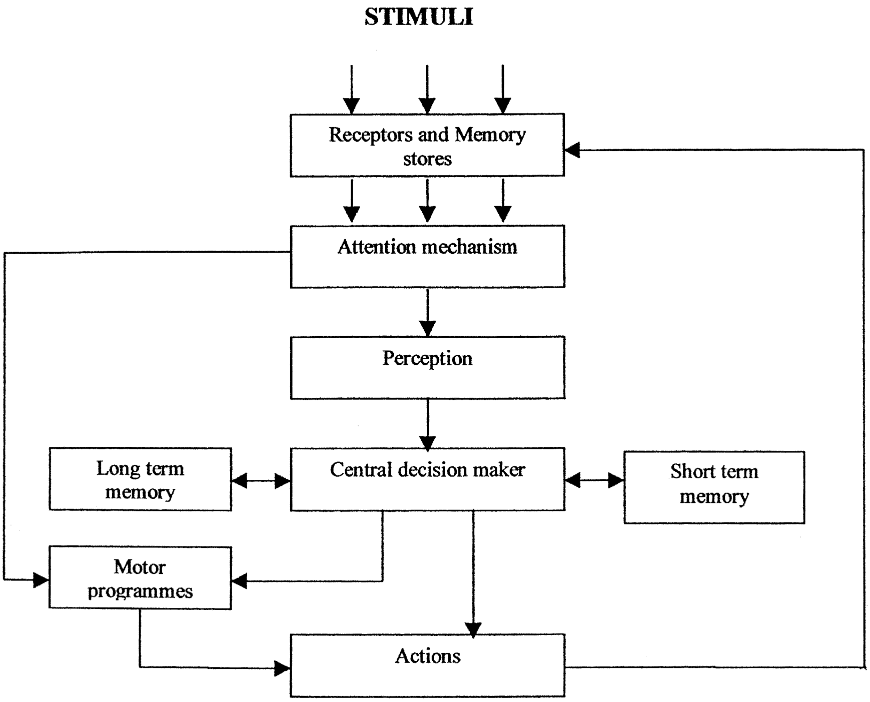

Fig. 5.2 Alternative model of human information processing.

5.1 Attention and vigilance

Attention is gained by a stimulus, usually derived from an information source. This source can be physical, e.g. the sound of a stall warner, or psychological, e.g. a thought which occurs in the mind, and which drives the information process in the brain to concentrate on a particular aspect. Man has limited capacity to process information, with the amount of information arriving at the sensory receptors far exceeding the processing capacity of the system. Attention can be selective in that it is normally possible to consciously process information from more than one source at a time by selective allocation of available mental resources (the cocktail party effect).

A second type of attention is divided attention. Unlike selective attention, when there is selective allocation of mental resources, during divided attention the whole resource is allocated to a portion of the task in hand.

Thus in the cockpit, it is impossible to concentrate on a radio transmission when simultaneously holding a conversation with another individual in the cockpit. Another example occurs during high workload when attention may be concentrated on a particularly demanding task and an aural alarm or visual warning is ignored because the information fails to be processed.

In performing a complex task, such as operating an aircraft, it is often necessary to divide or share attention between several information sources. Individuals differ in their capacity to allocate mental resources between different demands, and they differ in how this varies under conditions of high workload. It is a facility which develops with training and experience, but each individual has an ultimate finite capacity for multi-source information processing. Overload can result from a lack of understanding, when it is referred to as qualitative overload, or to the receipt of too much information, when it is referred to as quantitative overload.

Vigilance is the state of awareness of external sensory input, and is the degree of activation of the central nervous system. Attention is directly influenced by the level of vigilance, which can be reduced under conditions of both high and low workload. Hypo-vigilance is the condition of low sensory receptivity resulting from an arousal level deviating from the optimum, due to workload, stress or disrupted sleep pattern.

One theory of processing suggests that the information is broken into small portions or 'bits' which pass rapidly through a processing 'gate' or filter. This explains the ability to divide attention when the bit-streaming is interrupted by bits of information from other sensory systems. It also explains some errors when bits are processed out of sequence, or bits of information from one information source become mixed at the gate with bits from another source.

An alternative theory suggests that information from the sensory systems is processed in distinct 'parcels' and processing occurs by rapid switching between these parcels of information.

Thus an individual can perform more than one activity at a time, provided that the combined demands of these activities do not exceed central processing capacity, and that the activities do not overload any of the sub-systems of the working memory.

The state of vigilance can be affected by the following factors:

- external sensory input or workload
- fatigue
- stress
- health
- motivation
- well-being (the earliest observable effect of carbon monoxide poisoning is a reduced state of vigilance).

Signs of reduced vigilance include:

- concentration on a single task at the expense of other input requirements
- poor communication in the cockpit
- irritability.

5.2 Perception

A pilot's physical actions are the motor response to what is perceived. Perception is derived from the sensory system, i.e. the eyes, the vestibular system of the inner ear and the proprioceptive system involving nerve endings in the skin, muscles and joints. Signals from these systems enable a mental model to be formed of the individual's orientation in space and, using experience and knowledge, the appropriate response is made.

Perceptual illusions

Perception is influenced by expectancy and anticipation and this can have a powerful bearing on what is perceived, which may in fact be at variance with the true situation.

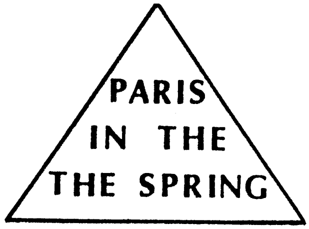

Fig. 5.3 Perception using top-down processing.

A quick glance at Figure 5.3 followed by a careful reading of the words is a good example of how expectancy based on existing experience can lead to errors in perception. The sensory information is utilised to form a mental model. This is based on past and existing experience and the second 'THE' is disregarded during processing by the visual cortex.

This is referred to as top-down processing. It is utilised in depth perception when smaller objects or objects nearer the horizon are perceived as being more distant than larger objects or those further from the horizon, because that is the expectation based on experience of the world around us. Top-down processing utilises existing hypotheses of reality to process incoming data.

Top-down perception is when the individual makes a scene fit what the imagination expects it to be. This can cause a type of cognitive failure which may lead to an accident or incident. For example, doing a wheels-up landing when there are no green gear-safe indicator lights illuminated. The pilot may 'see' them as green, because that was the expectation, when they are not, due to other factors causing a high workload.

Figure 5.4 illustrates another form of misperception, known as the Muller–Lyer illusion.

Although the left horizontal line looks shorter than the one on the right, they are actually both the same length. The visual cortex analyses the image using combinations of brain cells which respond to lines, edges, angles and ends. In this case, the pattern analysis

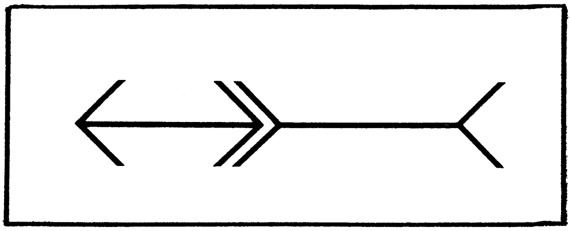

Fig. 5.4 The Muller–Lyer illusion, utilising bottom-up processing.

leads to an inappropriate perception of reality utilising the bottom-up pattern cues. Bottom-up information processing is driven by the nature of the environmental stimuli, and can be important during the approach and landing phase of a flight.

Expectation, or what is called 'set', has an influence on perception. In the first example, previous experience leads to a given mind set and so one reads what one expects to read. In the second example, the influence of angles and patterns lead to a perceptual illusion.

Bottom-up processing can be considered to be data-driven perception, whereas top-down processing is conceptually-driven perception. Using the two together leads to interactive processing.

Perceptual subjectivity

Perception is very much based on previous experience and knowledge which inevitably leads to subjectivity. This can also be influenced by individual wishes and desires. Thus two individuals may well perceive the same sensory information quite differently if they have dissimilar backgrounds, experience and training. Hence the importance of standard operating procedures and standardised training which ensures a constant experience and knowledge base. This leads to the development of appropriate moderation of filtering of the information to ensure the correct concept of reality. The filters of perception are past experience and learning.

5.3 Memory

Memory symbolises the mental faculty of retaining and recalling knowledge and past experiences. However, like so many human

functions, memory occurs in varying degrees and the level of recall varies between individual people and also in the same person from day to day.

It is the ability of the brain to register information, store it, associate it with previously stored information and recall it when needed. The brain consists of approximately 21 billion cells and these are joined by a complex series of linkages; it is the formation of these linkages which makes up the memory system. The same item of memory may be stored in a number of different brain cells and can be accessed by different linkage pathways. This explains why brain cells can be lost through age or damage, and yet clear memories of many past experiences are retained.

Human information processing can be considered as having three different information stores from which recall is made. These are referred to as the short-term memory (sensory memory), the long-term memory and the working memory. In addition, there is a motor memory which is used for the subconscious performance of learned skills. The position of the memory function in information processing is shown in Figures 5.1 and 5.2.

Short-term memory (sensory)

The *short-term memory* refers to information which is stored for a very short time and then forgotten. It is usually limited to a few items of information for a few seconds. An example of this would be the reading of a telephone number and then, due to a lack of recall, having to read it again before completing the dialling sequence. Figure 5.5 shows the approximate memory retention of a typical short-term recall ability.

The process of recall utilises a number of sensory stimuli, which affects the length of time that information is retained in memory. Iconic memory utilises image, and information is held in this type of memory for 0.5 to 1.0 second. Echoic memory forms words from sounds that resemble those associated with the object or action to be named, and retains information for 2 to 8 seconds. The working short-term memory can retain information for 10 to 20 seconds.

The maximum number of disassociated items which can normally be retained in the short term memory is nine, the normal retention being around seven items.

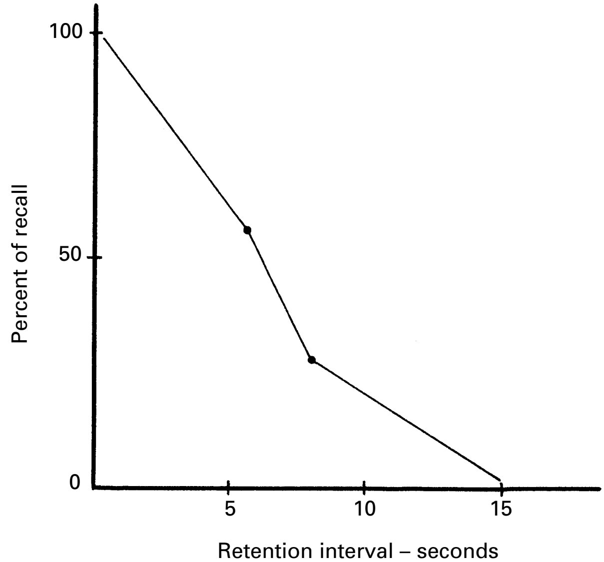

Fig. 5.5 Memory retention time of short-term recall.

Long-term memory

Long-term memory, as the expression indicates, represents the facility to recall information which has been stored either by repetition or constant recall (semantic memory), or by a vivid occurrence (episodic memory). It is episodic memory which is affected by amnesia. It can be considered as information which is not currently being used but is held in a high capacity store of all accumulated knowledge, being the store for rule-based behaviour. Nevertheless, long-term memory does have limitations and Figure 5.6 shows how the probability of recalling items increases with the number of recalls actually made. This form of memory improves with constant exercise of its function, and is the store for knowledge.

One method of improving recall is known as 'over learning'. It means carrying the training process beyond that required to perform an acceptable standard of performance at the time. This concept, built into any effective training programme, assists recall and also strengthens resistance to stress as well as improving psycho-motor tasks.

Another aspect of this form of memory is that continuous recall of specific items, or conducting motor tasks with a good level of continuity, enhances the ability to remember or carry out the tasks. This

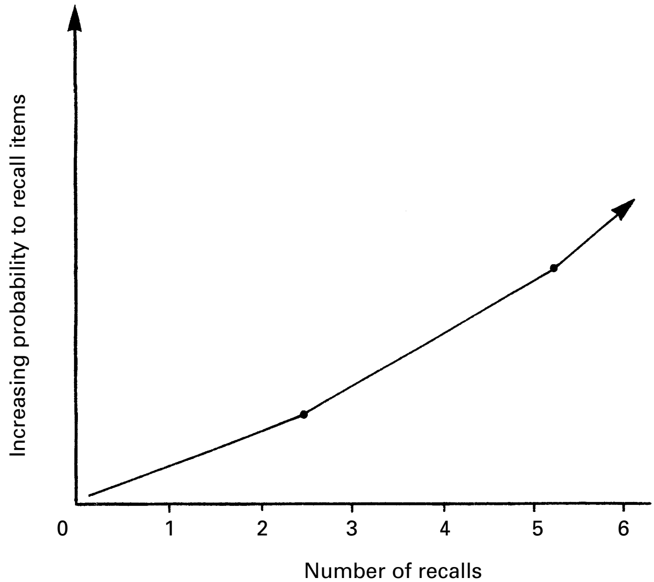

Fig. 5.6 Ability to remember items as function of recalls actually made.

is known as continuous activity. On the other hand, tasks which require separate responses (serial tasks), are more easily forgotten.

Working memory

The *working memory* utilises information currently in use. For example, when reading from a check list, working memory is using information from both short- and long-term memory stores to translate the meaning of words into the necessary cognitive and physical actions. An example is the decision as to whether or not flaps should be used for take-off, or the calculation of the fuel required for a particular flight.

Although short-term memory is normally restricted to recalling between six and eight items, it can be improved by 'chunking'. This is a method of taking unrelated letters and associating them with familiar words so the words can be remembered; if the words are extended into sentences many more words can be remembered. In a sense this is similar to the use of common mnemonics such as FREDA or HASELL which are introduced from the early stages of pilot training. The use of chunking is therefore a valuable tool to enhance working memory.

Other tools to assist retention of memory, in addition to chunking and mnemonics, include association of words or ideas, repetition, revision and research.

Motor memory (skills)

Motor or skills memory is sometimes referred to as pre-cognitive control. Training improves familiarity and enables a pilot to become completely familiar with the aircraft handling characteristics in a given situation. The skills develop and are refined so that precise motor actions are performed at the subconscious level.

5.4 Response selection

Learning principles and techniques

Learning can be defined as gaining an understanding of how a procedure works. There are three basic forms of learning:

(1) *Behaviouristic approach* – The Russian physiologist Pavlov demonstrated that by repeatedly presenting an unconditioned stimulus (such as food to a dog) in conjunction with a conditioned stimulus (such as a bell rung just before the food is presented), a subconsciously learned action would develop in response to the conditioned stimulus (the dog would salivate at the sound of the bell without the presence of food). In flying training a pilot can be similarly trained to react to a stimulus (such as an alarm warning) and carry out the appropriate learned procedure.

(2) *Cognitive approach* – This involves conceptual solutions based on previously learned habits. In flying training an example is where the pilot is taught to perform a particular type of approach following a certain type of equipment failure. The pilot knows how the aircraft can be expected to perform under the failure condition, and has to plan the approach and fly it. Feedback is achieved by how well the approach is flown and this is stored in the memory for future reference in a similar situation.

(3) *Modelling* – This form of learning involves repetition. In flying training the instructor will demonstrate a circuit and then expect the trainee pilot to emulate the actions.

An alternative is to consider that learning has four processes:

(1) *Operant* – this is the physical learning of the motor skills.
(2) *Insight* – this is penetration into the topic and development of understanding.
(3) *Imitation* – this is further development of motor skills by imitating actions.
(4) *Experience* – this is an extension of imitation, and utilises the operant and insight processes.

The factors necessary for the promotion of good quality learning include:

- quality of instruction
- motivation
- knowledge of results (feedback).

Traditionally, pilot training utilises knowledge, skill and experience. Knowledge has to be gained before a skill can be developed, and then improved by experience. Pilot training at the *ab initio* stage is based primarily on the development of perceptual and motor skills. A skill is the capacity to accomplish successfully something requiring special knowledge or ability. However, this implies that skills are not related just to physical activities, but to other factors such as social, intellectual, linguistic, etc. In aviation, the motor skills cover physical actions and the degree of dexterity with which they are performed, i.e. with what precision the pilot handles the controls to make the aircraft achieve the performance required. However, other equally important aviation skills include competence in pre-flight planning, navigation, aircraft engineering and maintenance, as well as the skills of other members of the aviation community such as the capability of air traffic controllers to produce safe and expeditious air traffic flow.

In all cases the degree of skill is achieved mainly by experience, which stems from regular practice, and it varies with the adaptability

and speed of learning of the individual (sometimes referred to as learning capacity). All types of training create behavioural changes and attitudes towards particular situations and problems. A given situation has to be perceived, the problem identified and the alternatives considered to combat the problem, before a sensible judgement can be arrived at and decision taken.

There are four categories of behavioural competence on which this is based, after the Jans Rasmussen SRK model of behaviour (skill, rule and knowledge based):

- *knowledge based* – depending on memory and recall
- *comprehension based* – relating to the measure of understanding
- *rule based* – actions determined by rules or procedures stored in long-term memory
- *skill based* – the technique of doing something, i.e. practical skill.

There are risks associated with each of these categories.

The risk associated with knowledge based behaviour is called *confirmation bias*. In a given situation a hypothesis will be formed to explain the circumstance, leading to a tendency to disregard any information which fails to confirm the chosen hypothesis. Even when several information sources confirm that the wrong hypothesis has been chosen, there is a marked reluctance to change the hypothesis.

The risk associated with comprehension based behaviour is that there may be misunderstanding of the reasons giving rise to a situation. Both the instructor and the trainee may assume that a correct understanding has been gained, but in fact this may not be so.

Rule based behaviour is associated with two risks:

Error of commission – occurs when, for example, the pilot misidentifies an auditory warning and performs an inappropriate procedure (such as reducing airspeed in response to what is perceived as an overspeed warning instead of a stall warning – see chapter 7, section 7.1).

Departure from standard operating procedures – an example could be failure to respond to a ground proximity warning in accordance with operational procedures.

Skill based behaviour is also associated with two risks:

Action slip – a pilot may make the correct initial decision in a situation, but inadvertently exercise the wrong skill. Failure to monitor the action means that the pilot remains completely unaware of the mistake made. An example could be shutting down the wrong engine in response to an engine problem.

Environmental capture (habituation) – a pilot who is exercising a skill frequently may become so captured by the repetition that there is a failure to realise that a conscious check of the skill exercised has not actually been performed. An example of this can occur when flying repeated circuits when the response 'three greens' is given to the landing gear selection, without actually seeing the green indicator lights. There are many instances of inadvertent wheels-up landing occurring as a result of this risk.

The decision arrived at will be a combination of mental and physical functions which may be affected by the constraint of time.

Cognitive judgement is the end result of perceiving a situation via the sensory system or memory. The situation is then assessed using the hierarchical order of the brain and a plan of action is decided. In doing this, a pilot will be using knowledge gained from previous experience and will be evaluating the ability of the aircraft and him or herself to carry out the plan of action, or will consider whether an alternative plan is preferable.

Flying training is partly a process of developing motor memory. This proceeds from the basic *cognitive phase* to the *associative phase*, when events and procedures become linked with past experience involving some conscious thought process. Finally, the *automatic phase* is reached when no conscious thought is required. The acquisition of skill in this manner allows mental processing capacity to be freed for other tasks such as the maintenance of situational awareness.

Motor programmes are also known as mental schemata. The advantage of a motor programme is that it needs no conscious thought and so frees up the mental processing resources for other activities. However, a conscious thought is required to start a motor programme, and this can be prone to error of behaviour (as described above).

In the implementation of knowledge, comprehension, rule or skill based functions, the brain is functioning as an error detecting and error correcting system. When subjected to misleading or insufficient information, it can also be an error generating system. Thus sensible decision making depends upon the quality of knowledge, skill and experience, together with sensory and cognitive perception.

The use of flight simulation, whether a simple desktop personal computer type or a full fidelity six axis simulator, is a valuable tool for flying training. An important role of training is the planning and anticipation of future actions, so that when an event occurs in reality, the trained pilot is likely to take the correct actions to resolve the situation. Flight simulators enable the pilot to be placed in unusual situations and experience the problems encountered, so that the learned responses can be applied if such a situation is encountered during flight.

Motivation

The eventual outcome is partly driven by motivation. This is the inspiration or stimulus which acts as an incentive to achieve the appropriate response or outcome. It varies between individuals and in different situations, and defines *why* rather than *how* actions are performed.

Motivation reflects the difference between what an individual can do and what the individual will do. It is motivation which sustains and terminates all important activities. It influences the level of performance, the efficiency achieved and the time devoted to an activity, and also affects arousal level and the consequent level of performance (see Chapter 10, section 10.1).

Three types of motivation have been identified, all of which may be relevant in the aviation environment.

Achievement motivation may be made up of three elements:

- *mastery* – the need to confront new challenges and surpass one's earlier performance
- *work* – reflecting the satisfaction which is gained from performance
- *competitiveness* – the drive to surpass the performance of others.

Another form of motivation is *affiliation motivation*, which is concerned with the desire to be liked and accepted by other people.

Power motivation reflects concern over the means of influencing the behaviour of another person.

An understanding of what motivates an individual or a group should enable optimum performance, and hence optimum flight safety, to be achieved. A high need to achieve has been associated with occupational success, and is another area where there are differences between individuals. (See also Chapter 9, section 9.2 (p. 151) for Maslow's hierarchy.)

Chapter 6
Human Error and Reliability

An error can occur as an isolated incident or may form part of a chain of events.

The mis-selection of a radio frequency can be quickly identified and corrected and the flight safety result of such an isolated error is minimal. On the other hand, an error in the calculation of fuel flow early in a flight plan can set in chain a series of events with an eventual catastrophic outcome. An error chain can also be precipitated by an incorrect motor action such as mis-selection of a switch or control.

A pilot performing circuit training failed to raise the landing gear after take-off due to distraction during the after take-off checks. In the pre-landing checks downwind, he operated the landing gear selector but failed to note that he had raised the gear instead of lowering it. On final approach, he expected to see three green indicator lights and failed to register that the lights were not illuminated. The wheels-up landing was the end of the error chain.

This is an example of environmental capture associated with skill based behaviour. (See section 5.4).

Once skills have been learned and become automatic, they are established in the motor memory. Modification of these skills requires retraining, but the original skill cannot be erased. Under high workload or period of stress, reversion to the original skill may occur which is inappropriate to the current situation.

Human error in aviation is currently being addressed with two aims:

- to minimise the occurrence of errors by ensuring optimum matching of the components of the SHEL model (see Chapter 1, section 1.1) with human characteristics (*error resistance*)

- to determine how to live with the errors which will inevitably remain as a result of human limitations (*error tolerance*).

Strategies employed include:

- more automation (e.g. enhanced ground proximity warning system – EGPWS)
- review of pilot performance monitored by the aircraft data recorder
- enhanced procedures for pilots to monitor aircraft automatic systems
- greater use of flight simulators
- improved automated warning devices.

6.1 Reliability of human behaviour

Human error has long been a common and accepted element of behaviour, with examples occurring throughout history. However, this has not always been accepted in aviation. The expectation that training and adherence to standard operating procedures would remove any source of error has, on occasions, led to the establishment of a 'blame culture' rather than an acceptance that human error will inevitably occur.

Fortunately, the fallibility of human behaviour is now recognised and systems and procedures are designed to minimise the effect of human error, rather than to assume it will not happen.

Similar errors will have different outcomes in different situations. For example, putting sugar instead of salt on a plate of vegetables is of no serious consequence, whereas refuelling a piston-engined aircraft with kerosene instead of aviation gasoline could have catastrophic results.

Error rate will vary according to the task and can be influenced by many factors, such as fatigue, sleep loss and motivation. However, in an appropriately designed system, a human operator can enhance reliability by virtue of vigilance and the flexibility of human behaviour.

6.2 Hypotheses of reality

An important contributor to human error is the false hypothesis or mistaken assumption. Examples include taking off without air traffic control clearance, because something occurred to give the pilot the false assumption that he had been properly cleared, or landing at the wrong airport because of similar runway patterns.

The false hypothesis can be extremely resistant to correction. Evidence contradicting the false hypothesis is rejected until it becomes overwhelming, by which time it may be too late. Having made a decision based on a false hypothesis, the individual has a tendency to stick with the decision and seek information to confirm that decision, even to the extent of ignoring clear evidence that the decision is incorrect. This is known as *confirmation bias*. This has been seen in the cockpit voice recordings following accidents, revealing that doubts expressed by some crew members were overruled by the strength of the belief in the false hypothesis.

Situations when a false hypothesis is likely to occur include the following.

- *When expectancy is high* – typically after long experience of a situation and failing to appreciate that the situation is different on this occasion.
- *When attention is diverted elsewhere* – concentration on a particular problem can lead to false assumptions about other aspects of the flight.
- *When it serves as a defence* – human nature is to avoid anxiety, so a hypothesis may be based on avoiding the difficult true situation such as deteriorating weather.
- *Following a period of high concentration* – relaxation follows a stressful period and caution is set aside.
- *The effects of motor memory* – the operation of the wrong switch or control in a similar way to the correct one, perhaps leading to shutting down the wrong engine.

6.3 Theory and model of human error

As we have seen, exercising a skill is a conscious decision normally made by the central decision maker as a result of information processing. The store of motor programmes appears able to utilise the sensory input and have access to the neural mechanisms controlling the motor output (muscles) without necessarily referring to the central decision maker. This means that automatic skills (e.g. walking, some aspects of driving or flying) can occur at the same time as an activity requiring conscious control (e.g. holding a conversation).

However, if the usually automatic skill becomes demanding and requires conscious input, the single-channelled processing capacity of the central decision maker is utilised removing the spare capacity available for the other conscious task. This preoccupation may lead the pilot to make the correct initial decision, inadvertently exercise the wrong skill, but fail to monitor his or her activity, such that there is no awareness of the error which has been made.

Errors are more likely when the individual is preoccupied or tired (reducing central capacity), or when good conditions have reduced arousal leading to relaxation of vigilance and self-monitoring.

Errors of skill rarely happen to trainees because they have to consciously think about what they are doing, unlike experienced pilots in whom so many skills have become automatic.

An error occurs because of a failure in processing. An active failure occurs when there is an absence of self-monitoring and a positive, though incorrect, action is taken. A latent failure is when there is the potential for error inherent in the planned action and the error occurs by virtue of omission. Thus a deliberate intended action can be inappropriate in a situation, giving rise to error, just as error can arise through the performance of an unintended action.

6.4 Error generation

Error generation can be influenced by internal and external factors.

Internal factors can be categorised as:

- improper technique
- overconfidence
- insufficient care
- inappropriate cognitive style.

The basic activity of a pilot follows a cycle of detection, diagnosis, decision and execution, and error can occur at any stage. The cognitive style of the individual may influence error generation, and the following patterns have been identified as leading to poor judgement:

- *anti-authority* – resents being told what to do
- *impulsivity* – reacts quickly without thinking through the consequences
- *invulnerability* – believes problems won't happen to him or her
- *macho* – belief in own ability to do the task
- *external control* – resignation and belief that the outcome cannot be influenced.

Recognition of these traits in oneself or other crew members should lead to a heightened awareness of the possibility of errors occurring. External factors influencing error generation are:

- ergonomics
- economics
- social environment.

Ergonomics

The design of the flight deck or cockpit is necessarily a compromise between economics, the need to accommodate the range of flight crew shapes and sizes, and the positioning of the instruments and controls for optimum functional reach without compromising lookout and the operation of the aircraft.

The measurement of the human body is known as anthropometry. Anthropometric data are available for male and female populations from which statistical distributions and statistical properties, such as means and confidence limits, can be determined. In designing aircraft cockpits and flight decks, the 5% and 95% confidence limits are considered reasonable bounds, meaning that those who fall outside this range may not be accommodated in the design. The limits are also expressed as the 5th and 95th percentiles.

Key dimensions are measured, such as overall height, knee height and functional reach. Measurements are static (the individual not performing any function), dynamic (the individual simulating

interaction with the cockpit environment) and contour (accurate operation of aircraft controls without inadvertent operation of others). An individual falling at one point on the distribution for one dimension (e.g. height) will not necessarily fall at the same point on the distribution for another dimension (e.g. functional reach).

The layout of the flight deck is designed to suit a population falling between the 5% confidence limit for females and the 95% limit for males, for key static, dynamic and contour measurements. This can give rise to problems due to the fact that different populations throughout the world are of different stature. Some compromise is inevitable.

The key reference point on the flight deck for the safe and efficient operation of the aircraft is the 'eye datum point' or 'design eye position'. When the pilot adjusts his or her seat to achieve this point, there should be optimum vision of controls and instrumentation and external visual reference without the need for excessive head movement. Sitting below the eye datum point decreases downward vision over the aircraft nose, and on the final stages of the landing approach sight of the undershoot is lost.

To accommodate the 5th to 95th percentile pilot population, the pilot seat must have a wide range of adjustment including up and down and tilt, as well as fore and aft. In addition to allowing the pilot to achieve the eye datum point, it must also provide comfortable support to enable the pilot to operate safely and efficiently without distraction from the seating. To reduce the possibility of backache, the lumbar support is designed to distribute spinal compression loads evenly over the inter-vertebral discs.

Great improvements have been made in modern instrument displays, including the development of digital instrumentation, but inevitably problems remain. The three needle display altimeter is easily misinterpreted, and the potential for fatal error is enhanced by the fact that the needle indicating tens of thousands of feet is smaller than that indicating thousands, which in turn is smaller than that indicating hundreds of feet.

Studies comparing the three pointer altimeter display with a digital display show a difficulty factor of 3:1 and an error rate of 20% over the digital. Although a small change in value is best displayed on a digital instrument, rate of change is best perceived on an analogue instrument (i.e. quantitative information is better suited to a digital display, while qualitative/comparative/rate information is

more suited to an analogue display). Modern altimeters have a digital display plus a single needle indicating hundreds of feet, giving the advantages of both display types.

Digital altimeters require the availability of alternating electrical current (AC), so they cannot be used in simple light aircraft which have only a DC electrical system.

Figure 6.1 illustrates a number of altimeters. Look at each for 5 seconds and interpret the indication.

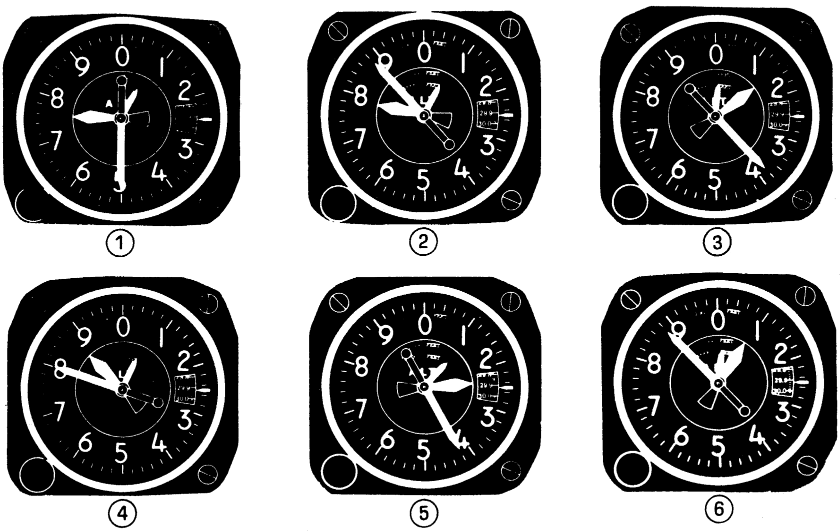

Fig. 6.1 Altimeters showing different heights for interpretation. (The correct answers are given on page 124.)

The need to scan the flight instruments to gain four-dimensional situational awareness (see Chapter 8, section 8.2) means that the pilot will only glance at the altimeter for a few seconds to monitor and correct any altitude deviation. However, the initial determination of altimeter reading requires more than a quick glance.

Standardisation exists for some aspects of instrument displays, but there is some variation between manufacturers, and standards have evolved with time. For example, the control knob used to set the pressure sub-scale on the altimeter is turned clockwise to increase the reading on some types of altimeter, but turned counter-clockwise to achieve the same result in other types.

When developing ‘glass cockpits’, one manufacturer in Europe

decided that the higher values for the linear speed scale should be placed at the top of the screen, whereas another manufacturer in the USA concluded that the higher values should be placed at the bottom of the scale. There were sound arguments for both, but eventually the European solution was adopted as the standard, but not before the potential for error and confusion had arisen.

Errors can arise from mis-selection of controls. There have been a number of instances where the landing gear has been raised rather than the flaps after landing, despite the landing gear selector control being shaped like a wheel and the flap control like a flap. This is an example of a false hypothesis not being influenced by a tactile cue, which is insufficiently strong to overcome the mind set leading to the erroneous selection.

Despite the potential for error, there is currently no requirement for objective evaluation of the human engineering (ergonomic) acceptability of instrumentation, and no mechanism for international standardisation. This is clearly an undesirable state of affairs, but pilots must remain vigilant to this source of error particularly under high work load.

Nonetheless, the importance of standardisation in the design of aircraft controls to reduce error generation is being increasingly recognised. For example:

- a handle or knob used to open a valve should always be designed to rotate in an anti-clockwise direction
- cockpit warnings should alert the flight crew but not startle them. Aural warnings are better for gaining attention, but visual warnings are better for leading the pilot to the correct location of the problem
- where a colour change is used to indicate a change of state, it should be accompanied by a change of caption or location.

Economics

The driving force in civil air operations is commercial pressure. It is obvious that to remain in business, an operator must make a profit. Similarly, the private pilot is under pressure to fly as cheaply as possible or to cut corners to reduce chargeable air time. There are continuing pressures on utilisation of aircraft and equipment, and on productivity of flight and ground personnel.

Answers to altimeter quiz

Altimeter readings: (1) 7,500 ft. (2) 7,880 ft. (3) 1,380 ft. (4) 8,800 ft. (5) 12,420 ft. (6) 880 ft.

In the 1950s the flight crew of a long-range airliner included two pilots, a flight navigator, a flight engineer and a radio operator. The crew now consists only of two pilots, the roles of navigator, radio operator and more recently the flight engineer having been supplanted by developing technology.

The driving force for the technological development has been cost reduction; a microprocessor is cheaper than a human crew member. It is also more efficient at performing the routine tasks, but only when under the control of a human being. Similarly, the evolution of electronic flight instrument displays has been driven as much by the fact that a liquid crystal display is cheaper to build and maintain than a complex analogue mechanical instrument, as by the multi-functional capacity of the electronic display.

In themselves, these developments should not lead to an increase in error. However, the pilot now has a range of functional tasks to perform and there are fewer crew members to monitor and cross-check his or her actions. Commercial pressures require long working hours, which can lead to fatigue and reduced vigilance increasing the possibility of error.

Social environment

The task of the crew on a flight deck is to work together safely and effectively. This is influenced by the role or job of the individual crew members, the status and experience of the individuals, and their personalities.

The function of having more than one pilot on the flight deck is to reduce workload by task sharing, to produce consensus decision making, and to ensure cross-checking of actions to minimise error.

The influence of personality styles and crew co-ordination will be dealt with in Chapter 8. Suffice it to say at this point that the organisation and dynamics of the flight crew group can have a significant influence on error generation, with pressure exerted by the group upon the individual to conform to social norms, comply with direct requests, or obey authority.

Chapter 7

Decision Making

Although the human has a vast capacity for sensing information, the decision-making stage of the process consists of just one single channel, being time shared between the different inputs. While one piece of information is being processed, the others are held temporarily in the short-term memory store, from where they are retrieved at the appropriate time. The storage and retrieval operation can be affected by many factors and this gives a source of potential error.

Because of its limited capacity, the decision-making channel is vulnerable to overload. The consequent load shedding may be poorly managed and can result in important information being discarded or not used. Under high workload or stress, concentration on a single stimulus may occur with other important inputs being ignored. When this applies to visual sensation, it is known as perceptual tunnelling.

Thus it can be seen that the decision-making process has two major components. The *rational part* involves conscious thought and choice, whereas the *intuitive part* of the process utilises long-term memory stores.

Decision making is a step-by-step scientific process which is sometimes referred to as the judgement concept. The stages in making a decision are:

- diagnosis and definition of objective
- collection of information
- assessment of risk
- development and evaluation of options
- decision of appropriate course of action
- implementation
- review and evaluation of consequences
- feedback.

The four stages of information processing are:

- sensing
- perception
- decision making
- motor action (response).

Once the action has been taken there is feedback to ensure the efficient operation of the system. Inadequate or inappropriate feedback can interfere with the processing system, leading to errors.

7.1 Decision-making concepts

Decision making is the capability to properly choose responses in complex situations where several reactions are possible. It is a major component of situational awareness, airmanship and good flying judgement. It is thought to be naturally developed through experience, but there is some evidence that situational awareness, judgement and decision-making skills can be improved through structured training.

Structure phases

Decision making is concerned with problem solving behaviour which is based only partially on knowledge and skills. The structure phases are:

- considering the choice of alternatives (gathering information)
- taking the appropriate decision despite uncertainty (considering alternatives)
- using available information (such as instrumentation and situational awareness) to reach a decision and form the appropriate judgement (positive decision).

Limits

The efficiency of decision making is limited by a number of factors. These include the individual's mental model of the particular

situation, the application of heuristic methods of problem solving (proceeding by trial and error to discover the solution), assessment of probabilities and the ability to recognise personal limits of workload. All these are influenced by individual personality factors such as flexibility, creativity and social style (such as dominance).

Risk assessment

In 1901, Wilbur Wright stated: 'If you are looking for perfect safety, you will do well to sit on a fence and watch the birds'. But it is known that the fence will not collapse only by assessing its condition before it is sat upon, and even then the assessment may be wrong.

Risk is a normal part of daily life, and its assessment is a fundamental part of human behaviour. Risk has to be recognised, the alternatives weighed up and a balanced conclusion reached. In aviation, risk cannot be completely avoided but the penalties of taking unnecessary risks can be very high.

Before a risk can be assessed it must first be recognised, but failure of recognition sows the seeds of a hazardous situation. Because human behaviour varies widely between individuals and situations, there is no simple formula for learning how to recognise degrees of risk.

Indeed, the human is not good at assessing risk. Essentially one can recognise two types of risk:

- *objective* – this is external risk, the assessment of which is not influenced by the human being
- *subjective* – this is internal risk, which is coloured by the training and experience of the individual.

Flying training involves the development of motor skills plus the ability to make good decisions. In the early stages of learning it is logical to concentrate on motor skills and simple judgement, such as correctly positioning the aircraft in the traffic pattern, using the flying controls and throttle to achieve the correct flight path and speed, and judging the height of the aircraft during the landing flare.

The development of more complex judgements based on multiple factors occurs later in training because motor skills are developed by handling items which can be seen, felt and moved, whereas cognitive

judgements and decisions are more abstract, using intelligence, awareness and experience.

The four basic elements involved in the development of judgement are also involved in risk assessment:

- the pilot
- the aircraft
- environmental conditions
- available time.

The pilot

Judgement can be clouded by high stress levels which can affect pilot performance during flight. Stress is covered in Chapter 10, section 10.2, but the four basic stressors are:

- *Physical* – conditions associated with the pilot's immediate environment affecting physical well-being, such as temperature, noise, or vibration.
- *Physiological* – the pilot's physical condition in relation to factors such as fatigue or hunger.
- *Psychological* – the influence of emotion, workload and the need to make decisions.
- *Sociological* – emotional stresses arising away from the flying environment, such as marital problems or job pressures.

The positive capabilities in an individual's decision-making process are:

- creativity
- innovativity
- adaptability

The negative human capabilities, potentially giving rise to error are:

- false mental model
- incorrect motor programme
- lack of feedback.

The aircraft

Risk factors associated with the aircraft include its condition and suitability for the intended flight. The level of installed equipment and appropriate fuel calculations must all be taken into account during risk assessment.

Environmental conditions

The environment is a wide ranging risk element. It includes the prevailing and anticipated weather, and the regulations governing the operation of the aircraft within the airspace system.

Time

Time is a constraining influence on the other three elements involved in risk assessment. When time is perceived to be short, impulsive or inappropriate decisions are more likely to be made. Lack of time does not just add to risk but multiplies it, and the shorter the time available the more likely it is that risks will be increased. The stress factor increases linearly as the deadline approaches.

Risk assessment is a continuing process during the planning and execution of a flight. The four elements of judgement development can be additive and accumulate, and a continuous analysis is required to enable reduction or removal of increasing risk factors by taking positive and correct decisions at an early stage. There are two main components in balancing risk:

- *Intellectual* – using existing knowledge, although this may not always be correct or sufficient to enable efficient information processing.
- *Motivational* – the individual's attitude towards risk and how it is affected by other influences such as the need to get home or peer pressure.

Practical application of risk management

Managing risk involves good judgement and decision making, which is the result of appropriate thought processes. The following are examples of inappropriate thought processes leading to poor risk management.

- Many general aviation pilots take care to ensure a cover is fitted to the pitot head when a light aircraft is parked, and yet do not fit a cover to the fuel vent which is equally vulnerable to the ingress of insects and debris.
- Pre take-off power checks may be performed with one fuel tank selected, and the selection is changed for take-off. This leads to the situation of full power being demanded at a critical time from a fuel system which has not been checked at high flow.

It is not only low time general aviation pilots who find themselves in situations for which they appear to lack the necessary understanding. The following example is of an accident in 1974 to a Boeing 727 in the USA.

> *The aircraft crashed 12 minutes after departure from New York. At 16,000 ft (the altitude at which icing was encountered) the airspeed fell and the anti-stall stick shaker activated at a high nose attitude of 30° pitch. The indicated airspeed was 412 knots whereas the actual airspeed was 165 knots. The aircraft entered a stall and spin and was destroyed, killing all on board. The erroneous airspeed was the result of a blockage in the pitot heads caused by icing, because the crew had overlooked the need to activate the pitot head heaters. The crew incorrectly diagnosed the stall warnings as Mach buffet (which occurs at high airspeed) and proceeded to raise the aircraft nose to reduce airspeed, leading to the fatal stall and spin.*

The crew's situational awareness was flawed, and incorrect thought processing led to the wrong diagnosis. This was an error of commission using rule based behaviour (see section 5.4).

Risk management often involves making rapid choices, based on available information and knowledge.

> A VFR pilot faced with deteriorating weather ahead may have to make a rapid choice between continuing, diverting, or returning to the airfield of departure. Considerations in the decision-making process include time, money, inconvenience, perceived danger, and social or peer pressure. In the heat of the moment, even the concept of diversion may become confused – does it mean diverting track around the weather or does it mean diverting to an alternate airfield?

> A quickly detected, correctly diagnosed engine fire, followed by an appropriate decision to shut down the affected engine, can be nullified by a slip in performing the required action leading to a shut down of the good engine.

Errors in formulating the correct plan of action are referred to as mistakes, whereas errors in the execution of a plan are referred to as slips. However, the outcome is the same with the execution of an incorrect action, leading to a minor incident or a catastrophic accident depending on the circumstances.

A slip does not satisfy the operator's intent, although the intent was correct. Conversely a fault satisfies the operator's intent, but in this case the intent itself was incorrect.

Chapter 8
Avoiding and Managing Errors: Cockpit Management

All human beings are prone to make errors. Human error is a fact of life and cannot be removed totally by training. It is therefore important to incorporate backups and fail–safe procedures in safety critical areas in an attempt to overcome the results or the possibility of human error, and avoid the development of false hypotheses.

This concept must also be accepted in others. It is not helpful to flight safety to engender a culture of blame when an individual makes an error; rather it should be accepted as a normal human limitation and every effort should be made to learn from the error in an attempt to avoid repetition.

8.1 Error management

Despite improvements in training and operational procedures, errors will continue to occur. Error can be managed as follows:

- *avoidance* – recognition of human traits and weakness can lead to the development of strategies and operating techniques to avoid error generation
- *trapping* – having identified an error, its effect can be minimised by isolating or trapping the activity affected by the error
- *mitigating* – the consequences of the error can be reduced by taking action to prevent the development of an error chain.

The development of error is influenced by awareness, and this has three levels:

- *perception* – the receipt and interpretation of sensory input, such as sight and sound

- *comprehension* – this is having an understanding of the current situation
- *projection* – this is utilising the knowledge of the current situation to look ahead and understand how this will influence the next stage of events, including the consequences of any course of action.

To manage error successfully, the crew on a flight deck must utilise the following team skills:

- *briefing* – this is to identify potential problems
- *preparation* – this is planning for the expected sequence of events and making contingencies for the unexpected; it is sometimes referred to as 'staying ahead of the aircraft'
- *workload* – establishing and maintaining priorities helps individual members of the crew to avoid overload.

The same principles apply to single pilot operation, and self discipline is necessary to ensure that these stages are followed.

8.2 Safety awareness

Risk area awareness

The areas of greatest risk in flying are take-off, final descent and landing. Figures for accidents to corporate aircraft in the USA show that 27% of accidents occur during the final descent (which comprises 2% of total flight time), 20% occur during landing (1% of flight time), and 13% during take-off (1% of flight time). Thus 60% of the accidents occur during the 4% of time spent near the ground. Similar statistics are observed when examining the accident reports from other countries and in other areas of aviation activity.

For all sectors of aviation, the comparatively few accidents occurring during the cruise phase of flight frequently involve controlled flight into terrain (CFIT). This is an accident which occurs when an apparently serviceable aircraft is flown by a healthy crew into ground (often covered by cloud) (see Figure 8.1).

In all these areas of risk, accidents occur as a result of lack of skill, judgement, poor decision making, or a false perception of situational awareness.

Fig. 8.1 Controlled flight into terrain (CFIT).

Error proneness

Certain personality characteristics appear to be associated with increased likelihood of accident involvement, although there is no such thing as a single clearly defined accident-prone personality.

Accidents are sometimes found to be associated with aggressive, anti-social, or non-conforming behaviour. It has also been suggested that the neurotic extrovert is at greater risk of accident involvement than the stable introvert, although other studies show that introverts are more likely to be involved.

Different personality characteristics are likely to predispose individuals towards different types of error, so the identification of an error prone personality is difficult.

Different individuals react in different ways to high workload, fatigue and stress. There are individual variations in mental processing capacity, and it is important for an individual to identify when he or she is reaching the limit of capacity, and thus becoming prone to error.

Error sources

There are many sources of error in operating an aircraft, mostly due to failure in human processing or behaviour. It is incumbent on all members of a crew to be alert for error generated intrinsically in the aircraft, or extrinsically in the air traffic or engineering environments. Cross-checking and monitoring of the actions and behaviour of other individuals is an important aspect of maintaining flight safety.

In 1983, Rouse, a cybernetics engineer developed an error classification scheme. This sets out six categories of behaviour needed to accomplish a specific task; examples are given of where error may occur.

(1) Observation of system

- misinterpretation of correct readings
- failure to observe variables

(2) Choice of hypothesis

- hypothesis inconsistent with observations
- choice of irrelevant hypothesis

(3) Testing of hypothesis

- wrong conclusion reached
- correct conclusion rejected

(4) Choice of goal

- insufficiently specified
- counter productive

(5) Choice of procedure

- would achieve incorrect goal
- procedure not chosen

(6) Execution of procedure

- required step omitted
- steps executed in wrong order.

Thus opportunities for error arise at all stages of the activity cycle, and such a scheme is useful when evaluating errors which may occur using new technology.

Situational awareness

Situational awareness is when perception matches reality. It is the state of knowing where the aircraft is, where it has been and where it is going in terms of the four dimensions of flight (the fourth dimension being time).

This requires an understanding of the limitations of oneself, the aircraft and its associated equipment and requires a continuing update of the associated risks.

Situational awareness is developed by processing the information available and using the resulting perception to develop a four-dimensional mental model. It is based on perception – when this matches reality, one is situationally aware.

In flight, information is derived from the flight and performance instruments, and from radio transmissions made by other aircraft and air traffic control. Each instrument can give only limited information, e.g. air speed, direction, altitude, rate of climb, aircraft attitude etc. To gain true situational awareness, it is necessary to mentally integrate this visual and aural information to build the four-dimensional picture.

This process can never become fully automatic and always requires some conscious effort of thought. This process is therefore vulnerable during overload of the information processing system, such as might occur during high workload or when the pilot's well-being is below par.

8.3 Multi-crew co-ordination

The presence of more than one crew member in a cockpit or on a flight deck constitutes a team or a multi-crew. An awareness and understanding of the human factors influencing the working of the team will enhance performance and flight safety.

The crew must have a leader, whose personality, behaviour and management style will inevitably impact on the team dynamics. Similarly, the personalities and behaviour of the other team members will influence the team performance.

Effective co-ordination will depend upon effective co-operation and communication between the team members. This will differ between the flight training phase and the commercial flight operation. During training there is an expectation of error as skills are developed, whereas in commercial flight operation the monitoring and cross-checking function is a confirmation of expected and mutually understood actions.

Crew briefings

The purpose of crew briefings is to ensure that each member of the crew understands the responsibilities of each individual; this ensures that any unbriefed action during the flight can be rapidly questioned. Crew briefings should be held before every flight and given when required in response to situations occurring during the flight. To be effective, briefings should be short and contain less than ten ideas.

Checklists

Checklists are also known as flight reference cards (FRCs) or quick reference handbooks (QRHs). The purpose of a checklist is to enable the crew to carry out a procedure in a well-defined and orderly manner, ensuring that all the necessary actions are completed by challenge, response and visual cross-checking. Checklists should be readily to hand on the flight deck and easy to use. They should be of a suitable size for stowage and easy handling, and should utilise cross-referenced indexing, colour coding of pages by topic and dividing pages with protruding index tabs. Bold, upper case and italic text may be useful in conveying emphasis, but text in normal font is faster and easier to read.

Interruption of checks by external sources, such as a radio call, can lead to actions being missed. Another source of error in using routine checklists habitually, is that the response may become automatic rather than diligent. There is a danger that familiarity with the aircraft and its systems can lead to rapid dismissal of checklist items, and pilots must guard against this tendency. Pilots of single crew aeroplanes must take particular care in the absence of a colleague to cross-check actions.

8.4 Co-operation

Co-operation is defined as action taken as part of an overall strategy. Co-action is defined as action coincident with, but independent from, an overall strategy.

Group dynamics

The occupants of an aircraft cockpit or the crew on the flight deck of a commercial airliner make up an identifiable group. A functional group is a collection of individuals with different personalities and social backgrounds, working together to achieve the same outcome. In a professional flight crew, the group members will have experienced similar training and will have similar knowledge of operating procedures and standards, although there will be variations in individual experience levels. Their task is to work together safely and effectively. This can be enhanced by crew resource management (CRM) training.

Multi crew co-operation (MCC) training takes the elements of CRM a stage further. It puts flight crew members into a practical scenario where they learn to work together as a team, applying the psychological principles of CRM to ensure the safe and efficient operation of a multi-crew aircraft.

In any group, consideration has to be given to individual needs as well as to the needs of the group. In a professional flight crew the roles are normally well defined and understood, whereas in recreational flying there may be more opportunity for conflict and confusion as a result of different personality traits not being moderated by standardised procedures.

The purpose of having a crew on the flight deck is to reduce workload by enabling tasks to be shared. It may also enable better quality decisions to be made than would be made by one individual. Although the decision made by a group will generally be of better quality than the average decisions made by the members of the group, it will never improve upon the problem solving ability of the ablest member of the group. Synergy is the term used to describe the state where the group performance is compared with individual performance. Communication and co-operation are important elements in the achievement of good synergy. Considering a two pilot

crew, good synergy is when $1+1= >2$, and poor synergy is when $1+1= <2$.

Cohesion is the ability of the group to work together to achieve a task. However, when there is too much cohesion thinking as a group can have negative results.

The dynamics of the group will be affected by a number of variables, including the role or job of each individual, the status of the individuals, and their personalities. Other factors include conformity, compliance, risky shift and group duration.

Conformity

This refers to those occasions when an individual changes his or her behaviour towards the group norm. It can be influenced by social pressure within the group, and by the size of the opposing majority (the optimum number being just four).

Compliance

This refers to the likelihood of an individual's accession to the request or actions of another member in the group. It is influenced by the type or magnitude of a request which has been made previously. Thus compliance with a large or unreasonable request is more likely if it has been preceded by an even more unreasonable request. This suggests that processing the request includes some form of comparative analysis. It will also be influenced by the status of the individual making the request.

Risky shift

It can be shown that if the individual members of a group already hold an opinion about a particular course of action, the opinion of the group as a whole will be even stronger. This is a form of polarisation, and can lead to decision making which is insufficiently tempered by consideration of the attendant risks in a situation.

Group duration

The dynamics and behaviour of a group will be influenced by the length of time for which that group remains in existence. It is common for military crews to be 'constituted' which means that the group of individuals will stay together until separated by posting off the squadron. Thus they become very familiar with the ways in which individual group members work and behave.

On the other hand, the group members of a civilian airline crew may never have flown together, nor even previously met, before being required to function as an efficient and effective team. Thus the importance of adherence to standard operating procedures, to ensure that all members of the team know the role and actions to be expected of the others.

Leadership and management styles

For a group to work most effectively it must have a recognised leader and be a team which is prepared to follow that leader. A good leader will have the respect of the people with whom he or she works, including the other members of the flight crew, immediate managers and members of the supporting operating team. To develop a good team, the leader will delegate responsibilities when appropriate and consider the opinions of other team members, freely admitting when any mistake is made. Followership is the ability of an individual to effectively support a recognised leader by being a good team player. The best leaders also have the ability to act as good followers.

The pilot in command of the aircraft is the captain, and he or she will be leader of the flight deck group by virtue of status. A leader may be 'task oriented' (goal directed, G) or 'relationship oriented' (person directed, P), or may combine elements of both depending on individual personality.

This integration of task and relationship orientation was first proposed by Blake and Mouton in 1964, and is known as Blake and Mouton's grid theory. It is based on the concept that leaders vary on an arbitrary scale from 1 to 9 in their concern for people (relationships) and their concern for getting things done (tasks). A grid can be constructed using 'goal/task' as the Y axis and 'people' as the X axis, and this gives rise to five main styles of leadership:

(1) *Authority-obedience* (9 on the Goal scale, 1 on the People scale – 9,1 or G+) – dictates how a job should be done.

This individual would show maximum concern for task completion with a minimum concern for people. The leadership style may be dominant, opinionated, aggressive and stubborn. This leader would run an authoritarian cockpit.

(2) *'Country Club' management* (1,9 or P+) – gets everybody talking at the expense of getting the job done.

This type of leader would show maximum concern for people, even at the expense of achieving results. The leadership style would be practical, trusting, friendly and accommodating, but would not voice qualms.

(3) *Impoverished management* (1,1 or P – G –) – no interest in the task or the people.

An individual with this style is putting forward only the least effort to remain within an organisation, with minimum concern for tasks or people. The way the cockpit was managed would be 'laissez-faire', implying a complete abstention from interference with individual action. This is potentially a dangerous situation.

(4) *Company Man* (5,5 or P+/ – G+/ –) – goes along to get along.

An individual with this leadership style just maintains the middle line, avoiding conflict, which results in conforming with the status quo.

(5) *Team management* (9,9 or P+G+) – goal and people centred.

This leader integrates concern for the task and concern for people at a high level, and achieves the goal through the participation, involvement and commitment of all those who can contribute. This would lead to a synergistic cockpit. However, there can be a danger of paternalism when the leader expresses a strong concern for the well-being of followers, but fails to consider their contributions to the task being completed.

The ideal leader will have a style which combines the extremes of either orientation (P+G+) and will be confident and relaxed, communicate and involve others, accept criticism, and be technically competent. Powers of command will be exercised in a way which gains the respect and commitment of all crew members, generating an atmosphere in which all members of the team feel that they are actively and positively contributing to the achievement of the goal.

Individual duty and role

In a single pilot operation, as in most recreational flying and much general aviation, the duty and role of the pilot is clear. However, in

the case of the crew on a flight deck, the individual roles of the crew members will influence interpersonal behaviour.

The role of the pilot will depend upon whether he or she is the nominated handling pilot for the particular sector of the flight. The captain retains command and ultimate responsibility for the conduct of the flight, but duties are shared. In general, the handling pilot is concerned with the physical control of the aircraft, while the non-handling pilot is responsible for communication with air traffic control, actioning checklist items, and monitoring the actions of the handling pilot. It is common practice for these roles to alternate between the pilots on consecutive flight sectors.

The monitoring role can be difficult, particularly if the non-handling pilot is junior or less experienced than the handling pilot. There has to be an understanding and acceptance by both pilots that it is entirely in order for the non-handling pilot to question the actions of the other and, if necessary, take over control. This acceptance will be facilitated by appropriate behaviour and leadership style.

Advantages and disadvantages of teamwork

Advantages

- a decision arrived at by a group is likely to be better quality than that derived by an individual
- flight safety should be enhanced
- workload is reduced by sharing
- work stress should be reduced.

Disadvantages

- personality clashes
- time taken to reach committee decision
- conformity
- risky shift.

8.5 Communication

The human state is such that communication is an integral part of interaction. This led Paul Watzlawick, a human factors commu-

nication expert, to state his first axiom of communication which is 'one cannot not communicate'. However, interpersonal communication is not without problems.

In a survey of 119 fatal accidents, the primary cause was given as inadequate communication in 41%. In any communication there must be a transmitter, a message, and a receiver. It is important that the receiver has time and space in which to interpret the message and respond accordingly. Thus it is the quality and not the quantity of communication which matters most on a busy flight deck.

Implicit communication is where various interpretations may be derived from the information conveyed. *Explicit communication*, on the other hand, is where the message is detailed with exact information and there is no ambiguity in interpretation of the message.

Because aviation is an international activity, in which participants are of different cultures and nationalities, it is important to use a universal professional language containing simple unambiguous words with well understood meaning. Any message used must be simple and explicit, and under international agreement this is based on English language technical or operational words and phrases ('aviation English'). It is important to avoid colloquial idiom during communication and to use standard phraseology.

Examples of misunderstanding during communication on the flight deck include:

(1) Captain: 'Take-off power.' First officer reduced power.
(2) Captain: 'Feather four.' First officer: 'All at once?'.
(3) Captain: 'Feather one.' First officer: 'Which one?'.
(4) Captain: 'Cheer up!' First officer raised the gear.
(5) Captain: 'Yaw damper.' First officer: 'My damper.'
(6) Air Traffic Controller: 'Say present heading.' First officer: 'Present heading.'

Communication models

During aural communication, an individual only actually listens to about a third of what is heard. This is because of the existence of the 'attention loop' – the first part of the communication is listened to, the information is evaluated, and a plan of action is formulated. This all takes mental processing time, which means that elements of the

message can be missed, or the listener may drop out of the attention loop for a short time.

Communication serves many functions in daily life, examples being:

- *instrumental function* – the object is to obtain something, such as a ticket purchase
- *informative function* – discover or explain something
- *ritual function* – part of a ceremony such as a wedding
- *persuasive function* – to modify an attitude or behaviour pattern.

The persuasive function of communication can be important in the flight deck environment and has three basic parts.

The originator

The originator must have credibility, which comprises expertise and trustworthiness. It is also important for the originator to believe in the validity of the message.

The message

The effectiveness of a message is influenced both by its content and by the manner in which it is presented.

Consideration of the content includes deciding on whether or not the message should contain both sides of the argument. If the receiver is already in broad agreement with the position being advocated, a one-sided argument may be more persuasive by reinforcing existing attitudes. On the other hand, if there is no existing agreement, putting both sides of the case may be more effective. Putting the positive arguments first is known as a primacy effect, whereas putting the more persuasive argument second is known as a recency effect. The way questions are phrased can also influence communication. There are three types: implicit (open), explicit (closed) and leading question.

The receiver

The final element in persuasive communication is the receiver. It has been suggested that a message modifying an individual's perception of an objective, rather than modifying his or her attitude towards it, may be more effective.

Berlo's communication model

The model by Berlo, a human factors communication expert, proposes that communication has four components, which are:

Source	Communication skills Knowledge Social system Culture Attitudes
Message	Elements Structure Content Treatment Code
Channel	Seeing Hearing Touching Smelling Taste
Receiver	Communication skills Knowledge Social system Culture Attitudes

It can be seen that the communication elements are identical for the source (originator) and the receiver, and that the channels of communication utilise all the human sensory pathways.

Schulz von Thun's communication model

Schulz von Thun, a German professor, proposes that there are four aspects of a verbal message which can be visualised on four sides of a rectangle:

(1) *Informational aspect* – level of facts.
(2) *Relational aspect* – level where one is telling something about the relationship between oneself and the other person.
(3) *Appelative aspect* – level where one tells the other person what to do.

(4) *Self-disclosure aspect* – level where one tells something about oneself.

These levels apply as much to the receiver as to the originator, and von Thun calls this the four ears of an individual. The fact that the originator and the receiver may weigh the levels differently if they are not explicitly expressed can become crucial.

An aircraft is taxying at a major airport and approaches a red stop bar. The captain says, ‘The stop bar is red’. This statement can be analysed in terms of the four levels:

(1) *Informational aspect* – ‘The stop bar is red’.
(2) *Relational aspect* – ‘I am in the position to tell you these things, and you have to listen carefully’ or ‘You are in a position to help me out of my confusion’.
(3) *Appelative aspect* – ‘Stop!’ or ‘Tell me why the stop bar is red’.
(4) *Self-disclosure aspect* – ‘I’ve seen the red stop bar and I have to tell you this’ or ‘I am wondering why the stop bar is red’.

It is necessary to have a context, given by non-verbal cues, to know how the different levels should be interpreted. In normal communication it is not important to analyse all messages on all levels. However, if problems arise, it is possible to move the message to the informational level of fact and redirect it to the speaker for clarification. From this it can be seen that the receiver is more critical than the transmitter, and the relational aspect tends to be most dominant.

Verbal and non-verbal communication

Verbal communication is the use of words and language to give and receive information. Language is inextricably linked with the cognitive or thinking processes as well as with communication.

Interpersonal relationships are influenced by the manner of speech as well as by the content. The manner, or paralanguage, includes voice pitch, word stress, timing and pauses. This can cause difficulties when communicating in a language which is not native to the speaker, such as may occur in the use of English as the international aviation language.

Non-verbal communication is also known as body language. This

involves communication using eye contact, facial expression, touch, body orientation and posture, hand and head movement, and physical separation ('personal space').

Communication barriers

One study of the importance attached to each communication method on how the sense of the message being received is picked up, showed that words were 7%, the way the words were said 38%, and body language 55%.

The flight deck environment inhibits these normal means of communication, particularly by restricting the use of non-verbal cues or body language. Thus communication between crew members has to be transmitted verbally, particularly at times of high workload or stress. However, during overload the verbal communication may not be processed (heard but not listened to) and vital information may be missed.

Communication may also be inhibited by an individual's personal style. Interruptions, and the ease with which one person gives way to the other, are indicative of dominance in a relationship.

An authoritarian individual is dogmatic and assertive, and communication from subordinates can be inhibited. Alternatively, a paternalistic style leads to frustration among the crew who feel that they are able to contribute little to the effective conduct of the operation, since they are not listened to. Perversely, the paternalistic individual believes that he is trying his best for the crew, and thus two-way communication is ineffective.

Effective communication is a skill which can be learned, but requires practice.

Conflict management

Conflict can arise because of inappropriate behaviour by other members of the group.

An intra-personal conflict is conflict within oneself, such as knowing what should be done in a situation and not wanting to do it. An inter-personal conflict, on the other hand, is conflict between two or more people.

If a conflict is destructive with no constructive solution, what started as a small difference of opinion can escalate into a major

confrontation involving other crew members and affecting flight safety.

The avoidance of conflict, and its solution when it occurs, can be assisted by the use of good communication practice:

- *inquiry* – ideas should be elicited and opinions taken from all crew members, with the leader avoiding giving an indication of his or her own ideas or opinion at the outset
- *active listening* – the ideas and opinions of all group members should be solicited, and any expressions of doubt should be encouraged
- *advocacy* – deal in evidence and not prejudice
- *feedback* – check to ensure the solution fits the scenario, reconfiguring if required
- *metacommunication* – use all channels of communication, including body language, facial expression, gestures, tone and pitch of voice, but avoid emotion
- *negotiation* – reach a solution by discussion with both sides
- *arbitration* – arrive at a solution acceptable to both sides, by using an independent uninvolved individual.

Chapter 9
Personality

9.1 Personality and attitudes

Personality describes the enduring predispositions which lead an individual to behave in particular ways. 'States' represent transient changes in behaviour or mood, whereas 'traits' are the characteristics of an individual which comprise the personality.

Behaviour is what other people see, and on which they base their judgement, whereas personality is made up of the traits with which an individual is born and further develops during the formative years. An individual is able to choose behaviour, but it is difficult to modify inherent personality characteristics which are genetically determined.

Recognition of the requirement to adapt behaviour to meet the needs and expectations of others is part of the maturation process.

There are many ways of classifying personality, some of which take account of different types or categories of personality. One example is the system of Eysenck who uses a statistical technique known as factor analysis to measure first level personality traits.

Factor analysis produces a table of inter-correlations between items to a small number of factors. The individual completes a series of questions known as a personality inventory and the correlation matrix for responses is subjected to factor analysis. An item is chosen for inclusion in the inventory if it loads strongly onto a particular factor and is not strongly associated with other factors. Eysenck describes three fundamental personality dimensions:

- extraversion
- neuroticism
- psychoticism.

An individual's score on any factor is independent of his or her scores on the upper factors. The major components of extraversion (E) are sociability and impulsiveness. Thus the extreme extrovert is outgoing, sociable and uninhibited. On the other hand the extreme introvert is reserved, shy and cautious. According to Eysenck, E is related to the excitability of the central nervous system.

The dimension of neuroticism (N), which extends from emotional stability to extreme anxiety and worry, may be associated with the lability of the autonomic nervous system.

Eysenck's final dimension of psychoticism (P), which indicates the degree of tough-mindedness and antipathy, is associated with the individual's drive. It extends from aggressive and anti-social behaviour to creativity and tough-mindedness, and the individual may be seen as cold and impulsive.

Another scale of assessment measures stability. Thus an unstable extrovert can be described as melancholic in personality type whereas a stable extrovert can be described as sanguine.

When personality is assessed it is found that successful pilots tend to be more stable than the general population and somewhat more extraverted. These characteristics are more extreme in military pilots than in civil pilots.

Development

During the formative years, children watch and imitate the behaviour of adults, leading to the development of models of how people in authority behave. This is known as 'parent mode'.

Similarly during development, children learn ways of dealing with figures of authority and expressing feelings and needs. This is known as 'child mode', and is centred on self.

These behaviours become instinctive and continue into adult life, where they can be inappropriate and lead to conflict.

The parent mode can be nurturing or critical.

The *nurturing parent* takes on all responsibility and can come across as patronising and demeaning in a professional environment. No respect is shown for the capabilities of the other individual who is actually encouraged to abrogate responsibility.

The *critical parent* comes across as dismissive, authoritarian and self-important.

Child mode behaviours can be equally ineffective.

The *adapted child* deals with authority by submitting in an obsequious, humble and anxious manner.

The *free child* demonstrates aggressive behaviour to rebel against authority in a destructive and sarcastic manner.

'Adult' mode is a consciously adopted objective response to a given interpersonal situation, utilising intellect rather than emotion. An individual demonstrating adult mode avoids preconceptions of others, is honest about his or her own feelings, and will respect the feelings of others. The intentions of others will be explored using questioning and listening skills, and consideration is given to the consequences of words and actions.

Environmental influences

The type of behavioural response is influenced by the behaviour observed. Thus the use of 'parent' behaviour often elicits a 'child' response.

Adult mode generally has the effect of neutralising both parent and child behaviours and leads to the adoption of similar rational behaviour. This is a useful tool in the management of conflict.

We have seen how the environment affects the normal means of communication, such as the inhibition of body language (non-verbal cues) on the flight deck. Thus it is important to use appropriate and effective 'adult mode' behaviour to enhance co-ordination of the flight crew group.

9.2 Individual differences in personality

One of the joys of the human race is individual differences in personality. Although this is a strength in social interaction and the richness of cultural variety, it may lead to problems in good judgement and decision making. In psychological terms, personalities can be broadly divided into introverts and extroverts, stable or neurotic.

Human performance cannot be predicted simply by measuring ability. Motivation takes account of the forces that lead an individual to pursue particular goals and reflects the difference between what a person can do and what the person will do. Maslow (1943) proposed a theory of motivation based on a hierarchy of needs. He

identified five needs and arranged them into a pyramid, with the lower levels representing the most powerful needs. At the lowest level are the physiological needs, including food, water, oxygen and sleep. The next level relates to security, which includes safety, financial security and job security. Moving up a stage, the third level relates to belonging or social interaction, which encompasses friendship and love. The fourth level is self-esteem or ego-autonomy, including recognition of skills and ability in the form of prestige, status and power. The top level at the apex is self-fulfilment or self-actualisation, in the expression of success in whatever terms the individual values. Maslow suggested that an individual strives to work upwards in the hierarchy, satisfying the needs at each level in turn.

Figure 9.1 shows Herzberg's theory of motivation which illustrates that two independent sources of motivation can contribute to performance in a work situation.

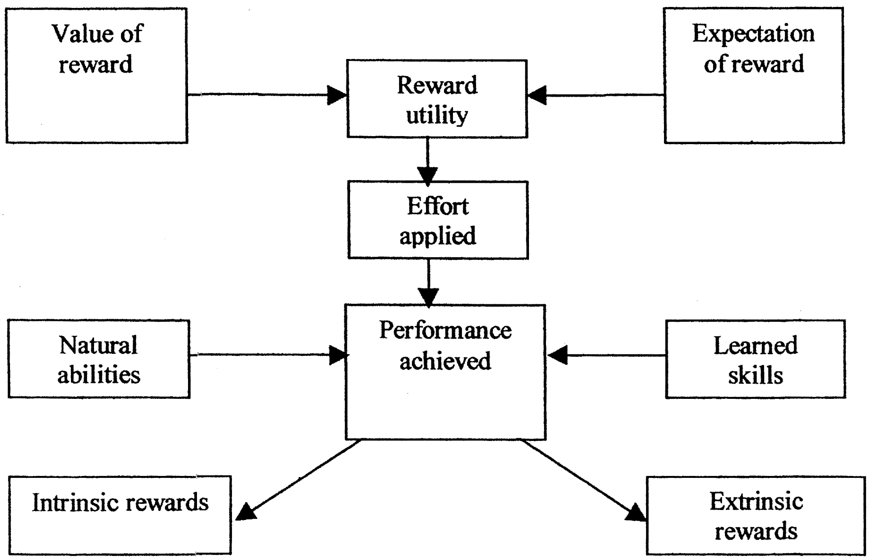

Fig. 9.1 Herzberg's theory of motivation.

The two sources are shown as being the perceived value of a reward and the probability of its attainment. Individuals place different values on rewards; one may value money very highly, while others may favour promotion, recognition or social status. If an

individual expects that the effort for attaining a reward will pass unnoticed, then it may be felt that the reward is of little use even though it may be valued highly by the individual.

A certain amount of effort will be required but this is not synonymous with performance. It is necessary to include two other variables, natural abilities and learned skills. From the performance, the rewards can be seen emerging.. These can be intrinsic, such as feelings of pride or achievement, or extrinsic, such as pay or promotion. If the rewards are seen to be tied to performance, higher job satisfaction will be achieved resulting in higher performance. Many people feel more content if they have clear targets to meet, and provided these are realistic, they too can contribute to job satisfaction. The main tools for increasing job satisfaction are job enrichment and job enlargement.

Self-esteem or self-concept is also an important factor in motivation. To have self-esteem is to respect and understand oneself, being aware of weaknesses as well as strengths. An individual with a positive self-concept will be able to accept personal mistakes or setbacks without shame, guilt or blame, and will accept the weaknesses and mistakes of others. As positive self-concept develops, the individual will feel less need to prove him or herself to others and will approach tasks without fear of failure or defeat.

Promotion from first officer to captain is perceived as reward, and will boost the first officer's self-esteem and self-concept. However, with that reward comes an increased level of responsibility and need for self discipline to maintain flight safety.

As well as individual personality differences there are also individual attitudes displayed by all types of personality.

Anti-authority

This stems from a feeling of resentment at being told what must or must not be done. It can lead to an individual disregarding regulations and standard procedures. If the individual considers the regulations or procedure to be unnecessarily complex or constraining, the anti-authoritarian behaviour can become habitual. This can lead to dilution of an ability to make sound decisions based on common sense. Peer pressure may be necessary to ensure compliance with safe operating practices and this includes balanced objectivity and restraint when making decisions. Safety demands a scrupulous observance of regulations and procedures, including pre-

flight aircraft inspection and assessment of one's own capabilities to make the flight in question.

Impulsiveness

This is the urge to do something immediately, when thought and time are in fact needed to arrive at a correct decision. An impulsive attitude prompts an individual to do the first thing that comes to mind without an analysis of the consequences or alternatives available.

One difficulty in overcoming this trait is that flying training leads to a large number of actions being carried out by rote, without any cognitive reasoning. For example, a pilot knows that the throttle needs to be advanced to obtain more power, an air traffic controller knows that his equipment has to be switched on before it can used and an engineer knows that to remove a nut from a bolt an appropriate spanner will be needed. The line dividing impulse and instinct is a thin one and positive effort and thought is often required to differentiate between the two. This differentiation can be developed with an increasing understanding and experience of the task involved.

Invulnerability

This is the feeling that one cannot actually influence a situation or the outcome of a series of events. It is often associated in a fundamental belief of good and bad luck and a willingness to go along with decisions and actions planned or made by others. A number of people subconsciously believe that accidents can only happen to others and never to themselves. These people are more likely to take chances and to incur unnecessary risks because they do not weigh up the possibilities of a hazardous situation occurring.

Other people know that events do not always go as planned and they remain in a continuous state of awareness as to what might happen. This is part of situational awareness and enables individuals to foresee possible situations at an early stage giving more time for analysis, possible alternatives and ultimately wiser decision making.

Machismo complex

This is related to having an excessively high opinion of oneself and is often demonstrated by displaying conceit and arrogance. Indivi-

duals demonstrating this behavioural attitude will normally do things on the basis of trying to prove that they are better than anyone else. They take risks to prove to themselves, as well as to others, that their assumption of their own ability is correct. Individuals with this exaggerated sense of their own ability often have extreme difficulties in controlling themselves or indeed being controlled by rules, regulations or other people.

Resignation

In this context resignation means the tendency to avoid making difficult choices or accepting responsibility. Individuals who resign themselves to the apparently inevitable do not see themselves making a great deal of difference to what happens to them.

When things go well or according to plan, these individuals ascribe it to good luck. When things go badly they usually attribute it to bad luck or feel that someone or something is 'out to get them'. Thus they have an innate sense of leaving decisions to others for better or worse. In essence this is a tendency to conform with group behaviour (conformity) and comply with the wishes of others (compliance). Sometimes this attitude can lead to the acceptance of an unreasonable or unsafe request in order not to appear to be a difficult person.

This attitude is often the result of under confidence and when any form of group decision is made by others there will be a natural tendency to be influenced and agree with that decision, whether or not it is a good one.

Aviators are generally gregarious by nature so there will often be the risk of following decisions made by others. This trait of shifting one's own responsibility on to others and accepting their decision is often called *risky shift*. Risky shift also implies that a decision taken by a group may often be less cautious than a decision that would have been made by any one individual of that group. So whether or not someone has an attitude of resignation, great care must be taken when agreeing to a group decision as it is often made on the degree of compromise between individuals. One should also be aware that stronger personalities within the group might well influence the final decision. It is important not to be influenced by others who have less regard for the risk than you do yourself.

Complacency

This trait can lead to a reduced awareness of danger. The high degree of automation and reliability in modern aircraft and equipment, and the routines involved in their operation can lead to complacency.

It often develops as pilots become experienced in a particular type of aircraft, procedure or operational activity. It originates in confidence which is an indispensable trait for the successful pilot. Pilots' confidence levels are determined by their past experience, training and personalities. As a pilot's learning curve on a new aircraft begins to flatten out, decisions become easier and flying becomes more routine and automatic.

When a pilot changes to a more complex or higher performance aircraft, the stresses during the transition are a strong motivator for acquiring the skills and knowledge necessary to master the new type of aircraft. As the combination of training and experience gives rise to confidence, however, the stress is no longer a factor and complacency frequently moves in to fill the void left by stress. Complacency may then be defined as a state of confidence plus contentment. The higher accident rate for general aviation pilots with between 1000 and 3000 flying hours, compared with those of less flying experience, is often explained by complacency.

The earliest symptoms of complacency are subtle erosions of the desire to remain proficient. The pre-flight checks become less complete and more automatic and items concerning personal safety are frequently neglected. The success in mastering the environment leads the pilot to become increasingly likely to play a flight 'by ear', rather than planning ahead for possible contingencies. The complacent pilot is usually unaware of the gradual deterioration in personal performance and so loses the ability for critical self-appraisal. This behaviour can be insidious and all pilots must remain alert to it.

Chapter 10
Human Overload and Underload

10.1 Arousal

An individual's arousal is the preparedness for performing any task. It is the degree of activation or alertness of the part of the brain known as the cortex.

Arousal and performance are related by an inverted U-shaped curve (known as the Yerkes–Dodson curve, or Yerkes–Dodson law) as shown in Figure 10.1. It can be considered that deep sleep forms one end of the arousal axis while sheer panic forms the other end, both of which result in poor performance. The optimum arousal for maximum performance is somewhere in between.

Many things will affect arousal; these include the individual's well-being, level of stress, mental overload, underload, etc.

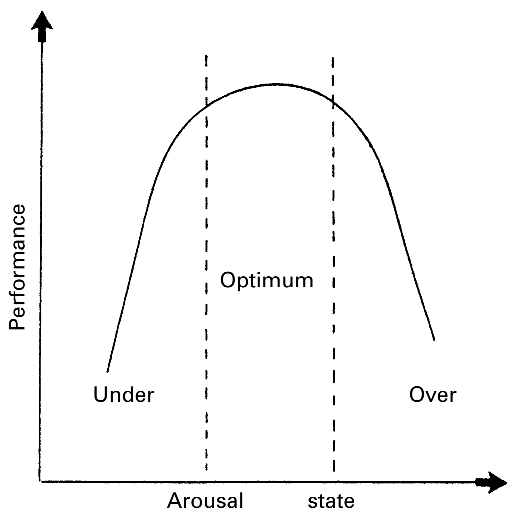

Fig. 10.1 The Yerkes–Dodson curve.

Other factors affecting the Yerkes–Dodson curve include the degree of difficulty of the task being performed, training and familiarity. The optimum level of arousal is inversely related to the difficulty of the task.

Although stress will influence the arousal state, the relationship between stress levels and performance is not a simple inverted U-shaped curve.

It is important to understand that under-arousal can have as much effect on performance as can over-arousal.

An example of under-arousal can be seen when flying in good weather in the cruise phase of flight where simple tasks take more effort than normal to complete. It is helpful to keep occupied with small 'housekeeping' tasks to try to maintain the arousal level in the area for optimum performance, so ensuring the best response in the event of an unexpected problem developing. Another example of under-arousal affecting performance can be seen when an approach to land is made in perfect weather conditions to a runway with which the pilot is very familiar, particularly when tired at the end of a long sector. Unless the handling pilot consciously raises his or her arousal level, an unexpectedly poor landing can occur.

10.2 Stress

Stress is the response to unfavourable environmental conditions, referred to as stressors, and describes how a body reacts to demands placed upon it. Stress applied to an airframe or power plant which exceeds the designed load factor leads to weakening or failure of the component affected. In the same way if excessive demands are placed on an individual, it is possible to exceed the individual's capacity to meet them. This results in a deterioration in the individual's ability to cope with the situation.

One model of stress is shown in Figure 10.2. This illustrates how stress can develop when an individual's perceived ability to perform a given task does not meet the demand. This gives rise to physiological (physical) and psychological (mental) responses which can affect the individual's performance. Physical stress occurs when external conditions either put a strain on the homeostatic mechanisms of the body or are so extreme as to nullify them. Mental stress occurs when the perceived demand exceeds the perceived ability.

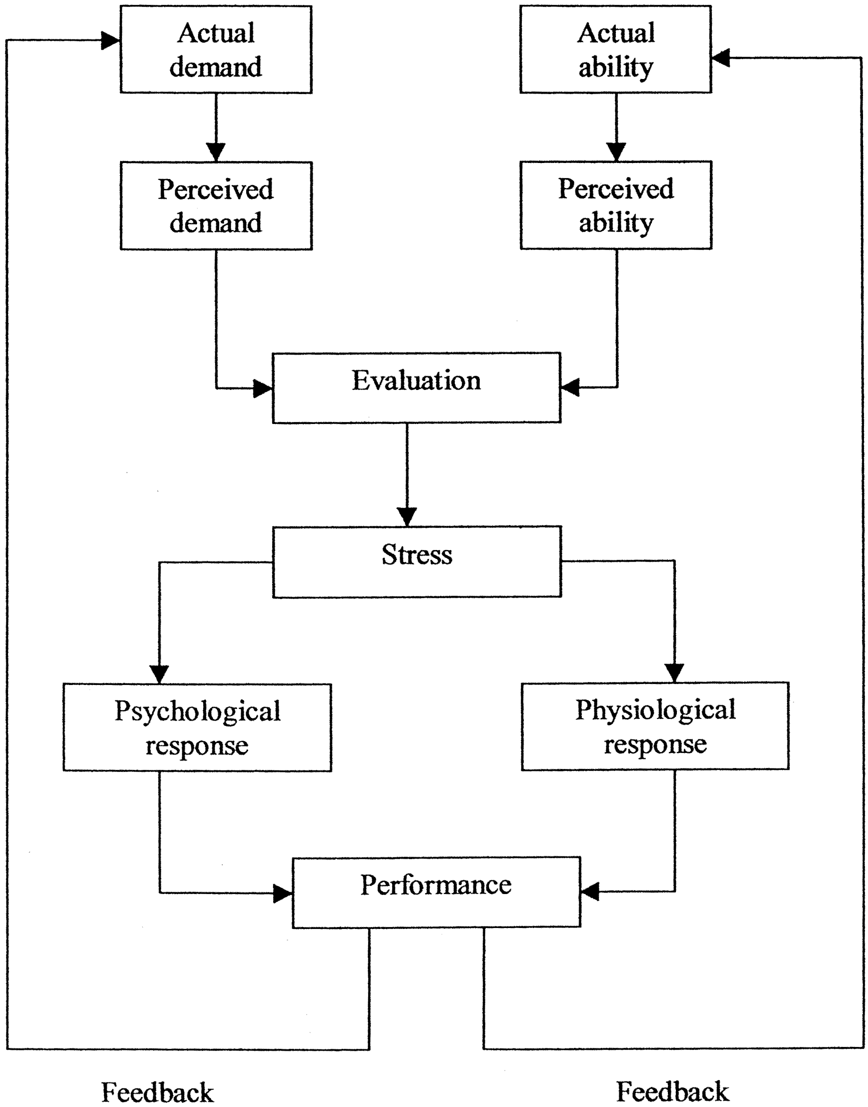

Fig. 10.2 Model of stress.

An individual can be likened in some ways to a bucket in that he or she has only a certain capacity. Once that capacity is exceeded, the bucket will overflow and will hold no more. Just as buckets come in different shapes and sizes, so different individuals have different capacities and abilities to cope.

Stress on a human being can be defined as:

- the body's non-specific response to demands placed upon it, whether these demands are pleasant or unpleasant
- an unresolved pressure, strain or force acting upon the individual's mental or physical systems which, if continued, will cause damage to those systems.

Thus continued stress can create physical symptoms such as insomnia, loss of appetite, headache, irritability, etc. The stimulus for stress is known as a *stressor* which is the force producing a change in the self-regulating balance between the individual's internal and external environment.

This stimulus will demand a response which may be psychological or physiological. Thus we see that the stressor is the stimulus and the stress is the response to it.

Stress is an inescapable part of human life. It is impossible to live without experiencing some degree of stress, whether at home, during our work role or at leisure. Further, an optimum amount of stress is necessary for an individual to function efficiently and perform a given task such as flying an aeroplane.

Selye described two forms of stress. The first is 'eustress', which is associated with a feeling of increased energy and ability to deal with the stressor. It can be considered to be 'good stress' which stimulates and adapts the body. The second is 'distress', when the individual feels that events are out of control and there is an inability to cope. This is 'bad stress'.

Stress can be acute or chronic:

- acute stress is something sudden and unexpected such as an engine fire or losing one's wallet;
- chronic stress is something that continues for a long period of time such as financial difficulties or inter-personal relationship problems.

The response to acute stress takes three stages, known as Selye's general adaptation syndrome (GAS).

(1) Alarm reaction (psychological)

In the alarm stage the body recognises the stressor and prepares for fight or flight by the release of hormones (adrenaline and corticosteroids). These hormones increase the heart beat and the rate of

breathing, raise the blood sugar level, increase perspiration, and slow digestion. Depending on the degree of danger recognised, the alarm reaction may result in a burst of energy, greater muscular strength, heightened hearing and vision. This is the 'fight or flight' response produced by the sympathetic system of the autonomic nervous system (ANS).

(2) Resistance (psychosomatic)

In the resistance stage the body attempts to repair any damage caused by the stress, enabling it to adapt to sustained or chronic stressors such as extreme cold, hard physical labour or personal worries. If the stress continues over a long period, the body will attempt to maintain its arousal state of readiness by activating the parasympathetic system of the autonomic nervous system. This prolongs mobilisation, giving time to find a solution and restore the body when the perceived threat has passed.

(3) Exhaustion (somatic)

Exhaustion is short-lived and affects those parts of the body which have been involved in the resistance stage. If the combination of resistance and exhaustion continues without relief over a long period, physical symptoms may develop such as raised blood pressure, headaches or indigestion.

Stressors

The total stress which can be imposed on the individual can be considered as from four sources.

(1) Environmental (physical)

These stressors are related to normal events which may occur during flying operations.

They may occur singly or collectively, and can be created by noise, vibration, heat, lack of oxygen, presence of carbon monoxide, the onset of fatigue, etc. Others are directly related to the tasks involved in flying, and the degree of stress will vary from flight to flight, and for different stages of the flight.

The potential main environmental sources of stress on the flight deck are:

- *Temperature* 20°C – comfortable temperature for most people in normal clothing
  >30°C – increased heart rate, blood pressure and sweating
  <15°C – discomfort, loss of feeling in hands, poor control of fine muscle movement
- *Vibration* Different parts of the body show a natural resonance at different periods of vibration. For example, the natural resonance of the eyeball is 30–40 Hz, and the skull is 1–4 Hz. Effects of vibration include:
  1–4 Hz – interference with breathing, neck pain
  4–10 Hz – chest and abdominal pain
  8–12 Hz – backache
  10–20 Hz – headache, eyestrain, throat pain, speech difficulty, muscle tension
  30–40 Hz – interference with vision
- *Noise* >80 dB – task performance may be impaired
  >90 dB – measurable impairment of task performance
  However, it has been shown that in some situations performance of vigilance tasks can actually be better in high noise levels than in low levels. This is because noise increases arousal and can move the individual into the optimum performance area of the Yerkes-Dodson inverted U curve.
- *Humidity* 40–60% – normal
  <20% – minor discomfort, such as skin, eye, nose, throat dryness
- *Glare* UV radiation from sunlight can cause visual fatigue.

(2) Life (psychological)

These stressors include causes such as emotional, domestic, social and financial.

These are associated with events in everyday life. They are wide-ranging and may include such factors as domestic and financial pressures which most of us face on a recurring basis. Family arguments, death of a close relative, inability to pay bills, lifestyle and personal activities, smoking or drinking to excess and other factors which may affect physical and mental health, all contribute to life stress which is part of everyday living. These can add significantly to the operational stressors which are part of flying activities.

Stress can also arise from physiological factors such as hunger, thirst, pain, lack of sleep and fatigue.

There have been many attempts to quantify the stress effect of life or domestic events. Once such scheme scores stress by totalling points, as follows:

Death of a spouse or partner	100
Divorce	73
Marital separation	65
Death of a close family member	63
Personal injury or illness	53
Loss of job	47
Retirement	45
Pregnancy	40
Sexual problems	40
Son or daughter leaving home	29
Change of residence	20
Bank loan or credit card debt	17
Vacation	13
Minor law violation	11

The cumulative points score gives an indication of life stress:

<60	–	Free of life stress
60-80	–	Normal life stress
80–100	–	High life stress
>100	–	Under serious life stress

(3) Reactive

These are the body's physical or mental response to situations which arise in everyday life, as well as those which arise when operating an aircraft. They stem from the body's reaction to a specific event. Examples in aviation are encountering wind shear on finals or running short of fuel.

(4) Organisational

Stress can arise from within the company or organisation for which an individual works. Certain organisational conditions have been identified as potential stressors. These include:

- poor communication
- role conflict or ambiguity
- workload and autonomy
- relationships with others
- lack of career development
- pay inequality
- bureaucratic processes.

Organisational stress in the aviation industry can affect flight safety. It can be avoided when the company is proactive in giving attention to the listed factors and provides support for employees.

A major stressor for pilots in modern aviation is insufficient hands-on flying.

Stress overload

Stress factors or stressors are cumulative and additive. Each individual has a personal stress limit and if this is exceeded, stress overload occurs which can result in an inability to handle even moderate workload. This personal stress limit varies with different people, as it is affected by an individual's physiological and psychological characteristics. For example, some individuals have the ability to switch off and relax, thus reducing the effects of stressors. Others are not so well equipped and the stress level increases to an unacceptable degree. When it happens to individuals working in a safety related environment, such as pilots, air traffic controllers or aircraft engineers, it can have serious effects in terms of flight safety.

It is common for an individual to believe that admitting to suffering from pressure is an admission of failure of ability to meet the demands of the job. It has long been an accepted culture in aviation that flight crew and others should be able to cope with any pressure or any situation, and training is directed at developing this capability in the individual – the 'can do' attitude.

Too often an individual, or his or her managers, will fail to recognise or to accept the emerging existence of stress-related symptoms. Denial is common, in a misguided attempt to maintain self-esteem. Once the symptoms are apparent, behavioural changes such as aggression or alcohol dependence may have become established. Such behaviour may lead to disciplinary action, which

could have been avoided by early recognition of the developing situation and appropriate intervention and support.

Anxiety and its relationship to stress

Anxiety creates worry, and in turn any form of worry may lead to stress. Imaginary stress is sometimes referred to as anxiety. Anxiety may be produced by an individual knowing that he or she has no control over specific effects, or that he or she lacks the knowledge to handle such events. It is particularly prevalent in people who, for one reason or another, are lacking in self confidence. It can be changed by increasing knowledge and gaining greater proficiency in operating an aircraft, which requires more time devoted to study and flight training.

Attitudes and general mental state have a direct influence on an individual's well-being. Psychological and emotional factors such as fear, anger, frustration, worry and anxiety may, over a long period of time, begin to affect the physical aspects of an individual's state of well-being.

Stress and anxiety are an inevitable part of human life and in small amounts they are necessary to achieve optimum performance. It is nature's way of keeping an individual keyed up for a task, by helping concentration and making recognition of danger easier. On the other hand excessive stress levels lead to excessive anxiety and it is important that individuals are able to recognise this.

Effects of stress

Individuals respond in different ways to high stress loads. Apart from the effects on behaviour, such as aggression, irritability, dogmatism and frustration, various psychological mechanisms may come into play in an attempt to cope with the situation. They include the following:

- *Omission* – completely omitting a particular action, such as forgetting to lower the landing gear during an approach with high workload and additional distractions.
- *Error* – incorrect response to a given stimulus, such as switching off the anti-collision beacon instead of the electric fuel pump.

- *Queuing* – sequentially delaying necessary actions in an inappropriate order of attention priority, such as failing to action a checklist while dealing with complicated air traffic control instructions.
- *Filtering* – rejection of certain tasks because of overload, such as not identifying the navigation aids when setting up for an instrument approach.
- *Approximation* – making approximations in technique in an attempt to cope with all the tasks required in a short-term interval, such as accepting inaccuracies while flying an ILS approach.
- *Coning of attention* – with increasing stress, the attention scan closes in to a smaller field of awareness. This can lead to inability to integrate the available information, and may be seen in the breakdown of the instrument scan during high workload activity in instrument flying conditions.
- *Regression* – under stress, behaviour may regress to the earliest learnt, such as operating a control or selector in a manner which would have been appropriate to the previous type of aircraft flown but not the current one.
- *Escape* – the ultimate response to extreme levels of stress is to give up or freeze.

In addition to the psychological effects of stress, physical effects may occur which vary from one individual to another. Stress is often perceived by the brain as some form of threat, and indeed, if you are being chased by a sabre-toothed tiger who fancies you for dinner, it is a reasonable assumption on the part of the brain.

The 'fight or flight' response has already been mentioned in which the primitive automatic responses for handling threatening situations come into play. Adrenaline is released, causing a rise in blood pressure, an increase in heart rate, deeper and more rapid breathing and an increase in tone of the larger muscle groups. Hormones known as corticosteroids are also released, making available stored sugars for increased energy use. The body is now ready for fight or flight (escape). Unfortunately, this is often an inappropriate response and, because the situation has to be handled by mental

rather than physical effort, the excess adrenaline can result in muscle tremor, incoordination, excessive sweating, and, in extreme cases, mental confusion and dizziness. The effects of continuing stress or overload have already been mentioned.

Performance can therefore be severely compromised in many ways by high levels of stress. It is important to realise that stress is cumulative and the effects of stress from one situation can be transferred to a different situation.

The break point occurs when, if the stress continues, performance is degraded.

Stress management

As we have seen, a certain amount of stress is unavoidable and indeed in certain conditions, it may be beneficial in raising arousal and hence improving performance. However, stress overload can reduce performance and it is helpful to consider ways of dealing with stress and reducing its effects.

The first step in reducing stress is to recognise when one is approaching the normal stress limit; inevitably this is a personal evaluation based on an understanding of one's own personality and capacity.

In determining fitness to fly, the psychological and emotional part of well-being must be considered in addition to the physical. Flying training engenders self-confidence and a strong desire to complete the task in hand. It can be difficult therefore to recognise and admit that one may indeed be approaching the limit.

The maintenance of physical well-being can assist in developing resistance to stress.

Actions to deal with stress include the following:

- Recognise the factors which are combining to cause the stress. Assess your own situation to see which of these factors is present.
- Deal with those factors which can be removed. Some can be handled just by recognising them for what they are and mentally putting them aside.
- If stress is being produced by overload, pause to organise a list of priorities. Do not allow low priority problems to influence you when you are not intending to deal with them. In flight, follow

standard operating procedures and use checklists with which you are familiar.

- Manage your time. It helps to develop a cycle of activity, apportioning time to each item.
- When appropriate delegate duties and learn to offload.
- Involve other people in your problems. Communicating and avoiding isolation is an effective way of lowering the level of stressors.
- In situations of acute stress, learn to recognise what is occurring. Learn to 'let go' and to mentally and physically relax. It may help to consciously relax your muscles whenever you feel tense or stressed.
- If the situation allows, take a short break for refreshment or relaxation. In flight, hand over control to another crew member when this is possible.
- Physical fitness seems to make some people more stress resistant. Eating regular balanced meals and indulging in physical activity several times a week promotes general health.
- Be positive and tackle responsibilities and problems as they occur. Avoid the tendency to put things off in the hope they will go away.
- Development of an appropriate sense of humour can be an excellent way of avoiding emotional stress.
- Recognise your own limitations and avoid overcommitment.

Finally, remember that clear thinking, free from emotional or physical worries is essential for flight planning and the safe conduct of a flight. Accidents and incidents in flight often occur because the requirements of the task exceed the pilot's capabilities, and this is more likely to occur when the effects of life stresses reduce the capacity to cope.

Coping strategies

Coping is the process in which the individual either adjusts to the perceived demands of a situation or changes the situation itself.

Some of the strategies appear to be carried out subconsciously, and it is only when they are unsuccessful that the stressor is noticed. Individuals vary in their ability to cope.

Three coping strategies can be defined as follows.

Action coping

In this strategy the individual takes some action to reduce the stress either by removing the problem or altering the situation so that it becomes less demanding. The extreme is when the individual removes himself from the situation, for example by changing jobs or getting divorced.

Cognitive coping

This coping strategy is used when the situation cannot be changed. It involves reducing the emotional and physiological impact of the stress. This may be done by rationalisation or emotional and intellectual detachment from the situation. The effect is to change the perception of the problem even if the demand itself is no different.

System directing coping

This is a means of removing the symptoms of the stress by taking physical exercise, using drugs such as tobacco and alcohol or utilising other stress management techniques.

Stress management is the process by which an individual will adopt systems to assist the coping strategies. Stress management techniques include:

- *Health and fitness programmes*. Regular physical exercise assists some people with cognitive coping.
- *Relaxation techniques*. There are many forms of relaxation frequently involving progressive muscle relaxation and the use of mental imagery. Examples include meditation, self-hypnosis, biofeedback techniques and autogenics. Some or all of these can be helpful in enabling individuals to reduce anxiety and control tension.
- *Religious practices*. Many people find that some form of regular religious practice and its associated faith helps the ability to cope with stresses particularly major life events such as bereavement.

- *Counselling techniques*. Counselling can assist both cognitive and action coping by modifying the way a situation is perceived leading to appropriate behavioural change. It may involve anything from regular sessions with a professional counsellor to simply talking about a stress problem with a supportive friend or colleague.

10.3 Sleep and fatigue

Sleep is essential for restoring the normal balance between the different parts of the central nervous system.

In terms of a computer microprocessor, it may be thought of as being analogous to transferring the experiences from the preceding period of wakefulness, stored on a floppy disk, to the central neural store which can be likened to the computer hard disk. This frees up the floppy disk for use during the next period of wakefulness.

Also during sleep, the body's physical functions are rested and some renewal takes place. During sleep, sympathetic nervous activity decreases and the muscular tone becomes almost nil. The arterial blood pressure falls, the pulse rate decreases, the blood vessels in the skin dilate and the overall basal metabolic rate of the body falls by up to 20%.

On average, most humans physiologically need about 8 hours of sleep per night. However, in modern society most adults report an average of 7 to 7.5 hours sleep per night. Studies have shown that up to 75% of adults report daytime sleepiness, with nearly a third of them reporting severe levels which interfered with activities.

Sleep loss can be acute or cumulative. In an acute situation, sleep loss can occur either totally or as a partial loss. It can accumulate over time into what is referred to as 'sleep debt'. As little as two hours of sleep loss can result in impairment of performance and levels of alertness. Sleep loss leads to increased reaction time, reduced vigilance, cognitive slowing, memory problems, time-on-task decrements and optimum response decrements. It has also been shown that performance variability increases with sleep loss.

The normal sleep requirement is 8 hours in every 24-hour period, and it is possible to perform a simple calculation of sleep debt when this requirement is not achieved. As the sleep requirement is 8 hours, within a 24 hour period this leaves 16 hours available for

activity. Alternatively, this can be expressed as one sleep hour being good for two hours of wakeful activity. The maximum possible credit to offset against sleep debt is 8 sleep hours. It is not necessary to sleep for the exact number of hours in deficit to recover sleep debt. Most people find that a 'catch-up' sleep of one-third of the deficit is sufficient. Sleep debt can become cumulative, leading to decrement in alertness and performance if the deficit is not recovered within a reasonable time.

Stages of sleep

Sleep can be divided into five stages – stages 1 to 4 and rapid eye movement (REM) sleep (Fig. 10.3).

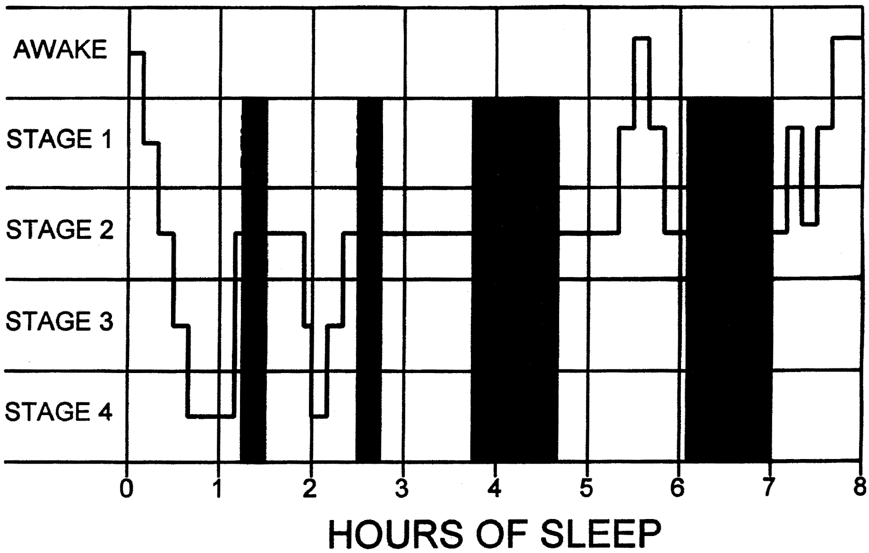

Fig. 10.3 Pattern of sleep over 8 hours (shaded areas are REM sleep).

Stage 1 is a transitional phase between waking and sleeping and this normally takes around 10 minutes as a person falls asleep. Sleep then becomes deeper with 15 minutes in stage 2 sleep and a further 15 minutes in stage 3 sleep before moving on to stage 4. Approximately 90 minutes after sleep onset, REM sleep will occur. The cycle of REM sleep and stages 1 to 4 sleep repeats during the course of the night in 90-minute cycles, each succeeding cycle containing

greater amounts of REM sleep. An 8-hour sleep period will typically contain about 4 or 5 bouts of REM sleep. Most stage 4 sleep happens early in the night.

The stages of sleep can be shown by examination of the eletroencephalogram (EEG), which measures electrical activity in the brain. The pattern changes for each stage, and stages 3 and 4 are referred to as 'slow wave' sleep from the shape of the EEG tracing. During an 8 hour period of sleep, 50% is usually made up of stage 2.

It is thought that the stages 1 to 4 sleep is related to body restoration whereas the REM sleep may be related to strengthening, refreshing and organising memory. When learning new tasks, an increased proportion of REM sleep is seen. REM sleep is sometimes referred to as 'paradoxic sleep'.

Performance and alertness

Besides sleep, the other major influence on waking performance and alertness is the internal circadian clock. Circadian rhythms fluctuate on a regular cycle which lasts something over 24 hours when allowed to 'free run'. The circadian rhythms are controlled by the suprachiasmatic nucleus of the hypothalamus situated in the brain, which is the timekeeper for a wide range of human functions, including physiological performance, behavioural mood and sleepiness/alertness. Many body functions have their own circadian rhythm and they are synchronised to a 24-hour pattern by 'zeitgebers' (time givers). Light has been demonstrated as being among the most powerful zeitgebers to synchronise the circadian pacemaker.

The mean normal body temperature is 37°C, but it has a natural cycle of less than 1° over the 24 hour period with a minimum at 06:00 hours, rising during the day to a maximum at 20:00 hours. In the normal rhythm, sleep would occur between 24:00 and 08:00 hours when body temperature is falling and reaching its low point. Therefore it is most difficult to work when body temperature is falling, and hardest to sleep when the body temperature is rising.

Moving to a new light/dark schedule (e.g. shift work or time zone changes) can create internal and external desynchronosis. This leads to a discrepancy between internal suprachiasmatic nucleus timing and external environmental cues. The internal clock can take days

or weeks to readjust, but generally requires one day for each time zone crossed or one day for every 90 minutes of jet-lag.

Crossing time zones is a way of life for long-haul flight crew, and constant time zone shifts can lead to cumulative sleep deprivation due to disruption of the body cycles known as circadian desynchronosis. This is also known as 'situational insomnia'. However, sleep debt and fatigue can also be a problem for short-haul crew as a result of very early starts and long multi-sector days.

Long-haul crew have to constantly adjust and readjust circadian rhythms, and the various intrinsic rhythms for temperature, digestion and excretion get out of phase with the rhythm for sleep. This leads to *jet lag* or *circadian dysrhythmia.*

Resynchronisation on westbound flights is aided by the body's normal circadian rhythm being nearer 25 hours, thus assisting the day to be 'stretched', whereas eastbound flights are more difficult due to the day being 'compressed'. Resynchronisation is easier when local time on landing is behind that at the airport of departure, whereas it is difficult when local time is ahead.

Fatigue can be defined as the likelihood of falling asleep. Therefore, in practical terms, there is little difference between chronic fatigue and acute tiredness. Fatigue can be caused by sleep loss and circadian desynchronosis, but it can also result from low motivation and low levels of external stimulation. In aviation, fatigue becomes important when it reduces efficiency and impairs performance.

In commercial aviation, fatigue is controlled by the imposition of flight time limitations. These do not apply in non-commercial flying but it is important to recognise the effect that fatigue or sleepiness can have on an individual's performance and limit flying time accordingly.

Schemes for flight time limitations are complex and take account of work rest schedules and previous duty periods. In the UK, current legislation is based on the Civil Aviation Authority publication CAP371 which was first issued in 1975. Other countries have similar schemes. Within Europe, the European Commission is developing a harmonised flight time limitations scheme which is planned to supersede national legislation.

Factors leading to the development of fatigue include early starts, night flying, a high number of sectors and long duty days for short-haul flight crew. For long-haul flight crew there is the additional

problem of long flight duration and regular crossing of time zones.

There are two principal components of sleepiness or fatigue:

- Physiological sleepiness or fatigue – this is a requirement like hunger or thirst and can only be reversed by sleep.
- Subjective sleepiness or fatigue – this is an individual's perception of his or her sleepiness but it may be affected by other factors. It may be difficult for an individual to subjectively assess his or her own alertness. In general, an individual overestimates the time taken to fall asleep and underestimates the total sleep time. Individuals tend to report a greater level of alertness than is actually the case.

Factors affecting sleepiness include:

- prior sleep and wakefulness
- circadian phase leading to
  - increased sleepiness in the early hours of the morning and during the afternoon
  - decreased performance in the early hours of the morning
- age (the amount of nocturnal sleep required reduces after the age of 50)
- alcohol (reduces the quality of sleep)
- work and environmental conditions.

Management of fatigue

Fatigue can be either short-term acute physiological or long-term chronic fatigue. Short-term fatigue is akin to tiredness and is usually a result of lack of sleep, hard physical or mental exertion, long duty period or jet lag. Chronic fatigue is much more difficult to recognise and quantify. It may be a result of lack of physical or mental fitness, domestic or work stress, financial problems and/or a high workload. It is subjective, with one individual being able to tolerate a greater level of stress than another before the onset of fatigue.

Fatigue gives rise to impaired performance and reduced levels of awareness.

Symptoms of fatigue

- tiredness

- slow reactions
- diminished motor skills
- diminished visual acuity
- reduced short term memory capacity
- channelled or tunnelled concentration

Effects of fatigue

- reduced awareness
- easy distraction
- poor instrument flying
- increased slips and mistakes
- abnormal mood swings.

Individuals have different needs and react differently to sleep loss. Therefore, each individual must apply recommendations to suit his or her own particular circumstances.

Preventative measures

Coping strategies for jet lag

Stop-over less than 24 hours – maintain eating and sleeping cycle on home time.

Stop-over of 24 hours – a difficult time interval to cope with. It does not allow time for two good 8 hour sleep periods, but is too long to cover with a single sleep session. The coping strategy may involve taking a limited rest period on arrival, and then a later longer period of sleep before call for duty.

Stop-over greater than 24 hours – it is important to gain sufficient sleep credit to complete the planned schedule, with an allowance for possible delays.

Sleep scheduling

- at home the best possible sleep should be obtained before a trip
- on a trip, as much sleep per 24 hours should be obtained as would be at home
- feelings should be trusted – if the individual feels sleepy and circumstances permit, then he or she should sleep. However, if the individual wakes spontaneously and cannot get to back to

sleep in about 15–30 minutes, then he or she should get up out of bed.

Good sleep habits

- a regular pre-sleep routine should be developed
- sleep time should be kept protected
- the individual should avoid going to bed hungry, but should not eat or drink heavily before going to bed
- alcohol or caffeine should be avoided before bedtime.

If necessary physical and mental relaxation techniques can be tried to aid falling asleep. If unable to go to sleep within 30 minutes, the individual should get up. An optimum dark, quiet and comfortable sleep environment is important. A healthy lifestyle with regular exercise should be maintained, which seems to help with the first stages of sleep.

Decreased wakefulness leads to a state of hypovigilance, which helps to control energy consumption by reducing activity of the central nervous system. Its total prevention in flight is not possible. Strategies for delaying the onset of hypovigilance during flight include:

- maintain sleep credit – always plan sleep patterns whenever possible
- be aware of the symptoms – drowsiness, slower sensory perception, preoccupation with an out of context problem, moodiness, reluctance to communicate
- alternate periods of activity and relaxation
- engage in social conversation
- engage in physical activity such as arm and leg stretching
- in a multi-crew operation, it is possible for crew members to take planned naps during the flight – these should not exceed 30–45 minutes, and recovery from a nap takes a period of 5 minutes.

Strategies for delaying or preventing the onset of fatigue include:

- keep fit
- eat regular balanced meals
- avoid regular use of alcohol
- ensure control of emotional and psychological aspects of life

- ensure adequate preparation for flight, including flight planning and flight deck comfort.

Caffeine consumption may be used to increase alertness. A cup of coffee usually takes about 15 to 30 minutes to become effective, and the effect lasts for between 3 and 4 hours. A balanced diet including drinking plenty of fluids can also help to prevent the onset of fatigue.

Bright light (more than 2,500 lux), used at the appropriate time in the circadian cycle, can help to reset the circadian clock.

After flying east, the traveller should be exposed to evening light with respect to body time, but morning light avoided. Conversely, when travelling west, morning light should be sought and evening light avoided. This makes the best use of the natural zeitgebers in resetting the body clock.

When used appropriately, certain drugs can help in the short-term to resynchronise the sleep cycle after time zone crossing.

Temazepam is a short acting benzodiazepine which is rapidly cleared from the body. Many people find this drug helpful in promoting sleep and, used for two or three days after travel, it can assist in resetting the sleep cycle. However, it should only be used under medical supervision and should never be taken within eight hours before flying as a member of crew.

Melatonin is a substance secreted by the pineal gland with a rhythm which is linked to the light/dark cycle through the suprachiasmatic nucleus. It is available in tablet form and has been used by many people to assist sleep. However, despite being a natural substance, the long-term side effects are not fully understood, particularly those affecting reproductive function and heart activity. It therefore does not have a pharmaceutical licence for general use.

Although alcohol is widely used by aircrew as an aid to sleep, it is a non-selective nervous system depressant and is effectively a drug. Although it may induce sleep, REM sleep is considerably reduced and early waking is likely. It is therefore not appropriate to use alcohol in this manner. It is also important to remember the after-effects on the vestibular system of even small amounts of alcohol.

Finally, it should be remembered that there is no simple or single solution for combating the effects of sleep loss and jet lag. The individual has to discover what helps him or her, and evolve the strategies to suit his or her particular needs.

Chapter 11
Advanced Cockpit Automation

Automation itself is not a new concept. Autopilots were introduced before the Second World War (1939–1945) and are now commonly found on most classes of aircraft, ranging from relatively unsophisticated light aeroplanes up to the highly automated flight deck of the modern commercial airliner. The technical complexities of modern aircraft plus the ever increasing complexity of the air space in which all aircraft operate has increased demands on the pilot and led to a steady increase in workload.

Basic navigational information is derived from the use of a map, a compass and a stop watch. However, this requires visual contact to be made with the surface and is only effective for relatively short distance navigation over land. The use of ground-based radio aids to provide relative bearing and distance information has become common since before the Second World War. However, the information derived from the cockpit indications has to be interpreted and integrated by the flight crew to provide situational awareness. The introduction of extremely precise inertial navigation systems to direct commercial aircraft over a predetermined course has rendered the role of flight navigator totally redundant. In non-commercial aircraft the use of global position systems, which derive navigational information from orbiting satellites, has reduced the demands on the general aviation pilot. Interpretation of information so derived is in some ways easier, but in turn, leads to new problems.

As well as automating the navigation of the aircraft and its actual control via the autopilot, another goal has been to optimise flight performance and manage fuel consumption. Continuously monitored and computer calculated throttle settings and flight paths can achieve significant fuel savings which have commercial benefits.

Finally, the display of information in the cockpit and on the flight deck has changed as evolution has occurred in the development of

electronics and microprocessors. Initially used in instruments, radios and navigation equipment, modern aircraft are now designed and built to make extensive use of microprocessing technology in control of aircraft and engines, as well as flight management systems and avionics. Instruments developed from the conventional mechanical clock, and standardised displays evolved. But mechanical clocks are expensive to build and to maintain, and their location on the instrument panel requires the pilot to actively scan the instruments in turn, interpret the reading and then integrate the information to arrive at the four-dimensional situational awareness. The development of electronic technology with cathode ray tube (CRT) displays and computer generated imagery, has inevitably led to multifunction information being presented on a single display. Navigational and weather information can be superimposed on primary flight information. This has the advantage of reducing the need to physically scan an instrument panel but has the obvious disadvantage of clutter and the need to interpret symbology.

Cockpit automation does not only apply to information display. In the early days of aviation the flying controls were operated by direct linkage from the control actuators in the cockpit. As aircraft size and speed increased, so the need for assistance from hydraulic systems evolved. This in turn has given way to fly-by-wire in which a control surface is appropriately deflected by a servo-motor system in response to the demands made from the flight deck. These demands may be as a result of direct input by the pilot, or from the autopilot which is performing the programme requested by the pilot.

All pilots undergo initial training on basic light aircraft. In this type of aircraft, the control column, the throttle lever or the flap lever are physically connected to the control surface, the fuel metering unit or the flaps, and deflection of the control causes the appropriate response by the aircraft. When flying a larger automated aircraft, the perception of the pilot remains that the physical deflection of the appropriate control is causing the appropriate response, even though the deflection has simply signalled the servo-motor system to act.

When the autopilot is in control of the aircraft, movement of the cockpit controls has provided reassurance to the monitoring pilot that the aircraft is doing what was expected.

However, as automation has evolved it has become accepted that

it is unnecessary for the cockpit controls to move in response to demands from the autopilot. An exception to this has been the implementation of auto throttle. First generations of auto throttle moved the levers in response to demands for thrust. However, this is seen by some manufacturers as an unnecessary complication in that the engine instruments will confirm the appropriate engine response and so the throttle levers no longer move in response to the demands of the auto throttle system. Some pilots find this disconcerting as with the unambiguous information given by a needle on a dial, so the position of a throttle lever in its quadrant is instinctively interpreted, based on past experience and training.

Different aircraft manufacturers have evolved different philosophies in the development of automation.

Airbus

- automation must not reduce overall aircraft reliability, but should enhance aircraft and system safety, efficiency and economy
- automation must not lead the aircraft out of the safe flight envelope, and it should be maintained within the normal flight envelope
- automation should allow the operator to use the safe flight envelope to its full extent, should this be necessary due to abnormal circumstances
- within the normal flight envelope, the automation must not work against operator inputs, except when absolutely necessary for safety.

Boeing

- the pilot is the final authority for the operation of the aircraft
- both crew members are ultimately responsible for the safe conduct of the flight
- the order of priority of flight crew tasks is safety, passenger comfort, efficiency
- design for crew operations is based on pilots' past training and operational experience
- systems designed to be error tolerant
- hierarchy of design alternatives is simplicity, redundancy, automation
- automation is a tool to aid, not replace, the pilot

- address fundamental human strengths, limitations and individual differences for both normal and abnormal operations
- use new technologies and functional capabilities only when they result in clear and distinct operational or efficiency advantages and there is no adverse effect on the human-machine interface.

There are advantages and disadvantages to aspects of both these philosophies, but the products of both manufacturers are in world-wide service and are recognised to be safe and efficient.

Advanced automation changes the nature of the human factor considerations on the flight deck. The flight crew need to remain effectively 'in the loop' as part of the system, so the interface between pilots and computers is crucial in keeping the pilots informed of the operation of the system and, conversely, keeping the computers informed of the condition and behaviour of the pilots. Although pilot workload has been significantly reduced on the one hand, in some cases there is the possibility that the new systems actually increase workload, albeit in a different area.

11.1 Advantages and disadvantages

Advantages

The major advantage of automation is the reduction in pilot workload associated with the manual task of flying and the associated cognitive processing. There is high accuracy and reliability of the systems and in general they are very cost effective. The use of multifunctional display allows increased sophistication of information presentation, which enhances accuracy, efficiency and the maintenance of situational awareness.

Disadvantages

Although the workload associated with manually flying and navigating the aircraft is reduced, the programming and monitoring of the automated systems can significantly increase workloads at critical phases of flight. However, during long-range cruise, workload may fall to such low levels that boredom occurs and arousal levels can reduce significantly. This can influence performance, particularly of vigilance tasks, and can reduce job satisfaction.

There is still no recognised international standardisation of the use of colour in multifunctional displays and there can be difficulties in designing an effective pilot/equipment interface.

Difficulties with automation can relate to system opacity, system autonomy and system protection.

System opacity increases with technology and gives poor mental representation of the underlying system function. It is based on the need-to-know principle in that the display to the crew shows only a simple tree which hides a forest of complexity. This is a great advantage for standard operations, but can be a limitation when things go wrong and the crew are unclear as to what can be done.

System autonomy means that the greater the technology, the more the system is able to adapt to a given situation without operator commands. This is particularly relevant in the function of the autopilot which can initiate a chain of events without direction from the pilot. This again is not a problem during normal operation, but if the pilot workload is high he or she may be outside the loop.

System protection is a built-in function to prevent errors from system malfunction. However, this can lead to the crew deviating from standard operating procedures because of fears that the system protection will lead the aircraft into dangerous modes of flight.

It has been suggested that these three problems can be solved by increased training. However, adaptation is slow, particularly when a pilot is transferring to fly an automated cockpit aircraft from a conventional type.

Another problem is the maintenance of manual and cognitive flying skills by the pilot. This remains an important requirement, because in the event of failure of the automated systems the pilot will use basic skills to fly the aircraft to a satisfactory landing.

Finally, there is the potential problem of boredom which can lead to hypovigilance and to a reduction in situational awareness. Pilots must learn to use automation to adjust workload to a level which maintains a certain amount of intellectual activity and keeps them in the loop. The system requires programming which is time consuming and the pilot needs to know how to do the simple tasks in real time. Human error can always occur. Hence the importance of a minimum two-crew operation in which one pilot monitors the actions of the other.

Advantages of the human over a machine are:

- creativeness
- innovation
- aptitude to deal with novel situations.

Human qualities which cannot be replaced by automation include:

- the capability of quickly grasping logical connections in large complex quantities of data and filtering out the meaningless data
- the ability to divide up memory into related data segments
- the ability to identify errors when data is presented graphically
- the possession of genuine flexibility in dealing with unforeseen events.

The Bainbridge ‘irony of automation’ is the paradox that automation does much better than the pilot those things that a pilot already knows how to do well. However it does not know at all how to do those things which the pilot would like to do well.

11.2 Automation complacency

Automation has sometimes been seen as an end in itself, rather than as a tool to enhance the aircraft operation. Excessive reliance on automation can lead to the symptom of automation complacency, where situational monitoring and cross-checking is reduced because of the belief in the infallibility of the automatic system.

The very reliability with which automated systems normally perform can lead to overconfidence and complacency.

An error during data input may not be picked up and corrected at the time. Subsequent cross-checking of the flight progress may reveal a disparity, but automation complacency may reinforce the hypothesis or mind set that the system ‘knows what it is doing’.

Alternatively, the belief in the system reliability may lead to an absence of cross-checking and a breakdown in the pilot’s situational awareness.

Monitoring may become passive whereby the inherent belief in the automated system’s infallibility leads to the individual simply watching what it is doing, rather than analysing and constantly checking. On the other hand, the multifunctional capability of the automated cockpit can lead to a narrowing of concentration on to

one particular aspect. This blinkered concentration leads to a breakdown in the monitoring of the whole system. Finally, the complexity of the automated system can lead to confusion and a loss of situational awareness. It is essential for the pilot to maintain ‘mode awareness’ to remain in the automation loop.

11.3 Working concepts

Situational awareness, in which the pilot has a mental picture of where the aircraft is in the four-dimensional environment, where it is going, and (crucially) awareness of the immediate environment, is developed as an advanced skill. It requires integration of information from the aircraft instrumentation and tactile feedback from aircraft behaviour, plus the maintenance of an appropriate level of arousal.

The new generation of automated aircraft has removed much of the requirement to exercise psychomotor skill, but the pilot remains in the control loop albeit performing a monitoring function. The pilot may be several stages removed from the physical control of the aircraft flight path, which is controlled by the information which has been programmed into the flight management system. Less raw data is presented to the pilot as a result of automation, and the opacity of the system means that the pilot may not be fully aware of what the aircraft systems are actually doing at any one time. This is a benefit when things are going as planned; it can be a problem when an unexpected situation or emergency develops, because it requires another stage in the pilot’s thinking process to maintain situational awareness.

It is the task of airline management to control the long-term risks of the company as a whole and the task of flight crew to control short-term risks encountered on individual flights. The co-ordination of these two is partly achieved by the development and use of standard operating procedures (SOPs). These SOPs marry the needs of the particular company with the checklists and standard drills issued by the aircraft manufacturer, and also incorporate the demands of the appropriate regulatory authority such as the CAA, FAA or JAA. In large companies, it is the case that individual members rarely fly together on a regular basis so it is important that all members of the crew follow and understand the SOP for any given operation or phase of flight.

The same constraints do not apply in the operation of general aviation aircraft. However, large numbers of small aircraft are complex and fitted with a large number of instruments, systems and avionic equipment. Thus it is important to develop standard operating procedures and the use of checklists in all spheres of aviation.

Routine drills and checks have a danger of becoming just that, and vigilance is required to maintain sufficient arousal to ensure correct drills are carried out. Errors may occur when a check sequence is interrupted, e.g. by a radio call, and the drill is resumed at the wrong place in the list. Another source of error can be the unthinking operation of a control or switch which was already at the required position; moving it to the other position in response to a checklist item can be inappropriate. Hence the importance of vigilant monitoring by other members of the crew and the development of self-monitoring and self-checking in single pilot operations.

Situational awareness is a constant and accurate perception of the factors and conditions affecting the aircraft and crew. It is knowing what is going on around you and the higher your state of situational awareness, the lower the risk of accident or incident. Automation can assist this process but should be viewed as a tool, not as an end in itself.

Albert Einstein is credited with saying:

'Computers are incredibly fast, accurate and stupid.
Humans are incredibly slow, inaccurate and brilliant.
Together, they are powerful beyond imagination.'

In Conclusion

Hopefully, the information given in this manual will not only supplement your existing knowledge, but will also strengthen your awareness of human weaknesses and how they can affect your endeavours to become a safe pilot.

It is easy for training to be seen as an end in itself. However, although flight training provides a pilot applicant with the required knowledge and skills to qualify for a licence or rating, just completing the required training and test is not the end, but just the beginning.

When a pilot steps into an aircraft, he or she needs to combine the technical knowledge, skills and procedures acquired both during and after training. Another important requirement is to know yourself and how you can make mistakes, particularly under stress. Equipped with this knowledge, the ability to think through flight situations in a sensible way and reduce the consequences of error will be the hallmark of any competent pilot.

A better understanding of how our physical condition and psychological processes interact with the various aspects of operating an aircraft will improve our performance and the safety of our passengers and ourselves, as well as providing fulfilment and pleasure from the activity of flying. This applies whether we fly for recreation or to earn a living.

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